

















# AMERICAN PETROLEUM REFINING



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263 ILLUSTRATIONS

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**AFFECTIONATELY DEDICATED  
TO MY WIFE  
MARION O. BELL**





## PREFACE

Notwithstanding the valuable literature of the petroleum industry, no volume has yet appeared which is devoted particularly to a presentation of information and data desired by the refiner. It is hoped that this publication will fill such existing need. The author's purpose has been to include herein the fundamental information of essential interest to the owner, manager or engineer contemplating installations of refinery equipment, and to the employee seeking knowledge beyond the scope of his present experience, perhaps confined to one or two particular operating departments.

The petroleum refining industry has in the past been characterized by an attitude of reluctance to exchange information between the many companies therein engaged. It is only recently that the benefits of cooperation on many of the ordinary problems of manufacturing have been recognized. For this reason, many of the statements herein may not agree with the experience of other individuals. If criticism and discussion result, with benefit to all, one purpose of the volume will have been fulfilled.

Until recent years, little attention has been given to efficiency in oil refining. It is hoped that the data and suggestions presented will encourage further effort to improve the conditions still existing in many of the refineries.

In a publication of this kind it is of course impossible to describe secret or semi-secret apparatus or processes; and nothing is divulged which has not been applied in practice by two or more independent companies.

The author wishes to express his great indebtedness to Mr. T. T. Gray for assistance in the preparation of the manuscript and for his collaboration with Mr. David Drogen in the preparation of Chapters III and IV on chemical and physical character-

istics of petroleum; also to Mr. W. D. Ennis for many valuable suggestions, and to Messrs. H. G. Larson and J. G. Brown for their assistance in the preparation of the drawings and manuscript. Appreciation is also expressed for data, drawings and photographs supplied by various oil companies and allied firms.

H. S. BELL.

ELIZABETH, N. J.,  
January 15, 1923.

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## CHAPTER I

### GENERAL INTRODUCTORY

The American petroleum industry may be said to have had its inception from the date of the drilling of the now famous Drake well: 1859. Prior to this date petroleum had been obtained in small quantities from brine wells in Pennsylvania. There is also the record of a flowing well in Kentucky, bored in 1814. Prior to 1858 these oils were used medicinally and as crude lubricants.

In the years from 1853 to 1858 the distillation of coal for illuminating and lubricating oils was exploited quite extensively in the United States, between fifty and sixty refineries being built. The plants followed the Scotch and English practice of the day. Inspired by the popularity of these products, Samuel Kier, a Pittsburgh druggist, using a crude adaptation of the coal-oil industry's apparatus, started the distillation of petroleum. His product was rapidly absorbed locally, and in 1858 the coal-oil refiners were tempted to try "rock oil" in their apparatus. Luther Atwood and Joshua Merrill, still famous in the industry, were favorably impressed; and the incentive was soon presented for the first undertaking with petroleum itself as the subject matter.

Accordingly, the Seneca Oil Company was formed. It acquired the rights of a previously organized concern, the Pennsylvania Rock Oil Company. The latter company had never succeeded, apparently from lack of confidence as to probable financial return. The impetus afforded by the prospect of treating petroleum in the coal-oil refineries was all that was needed, and on August 28, 1859, Drake's well "came in."

In sharp contrast to this humble beginning is the vast industry which has been built up in the past sixty years. Today this country is producing petroleum at the rate of 400,000,000 barrels a year, having a value in excess of that of any of our other

mineral products. There are in operation or under construction 472 petroleum refineries, over 50,000 miles of pipe line, and approximately 70,000 tank cars; while the tonnage of vessels on the high seas engaged in the transportation of petroleum and its products amounts to an amazing figure.

The organization of a well rounded-out concern engaged in the petroleum business includes production, transportation of crude oil, refining, transportation of finished products, and marketing. Very few existing concerns are involved in such a complete series of operations. Production is the leading department, with respect to the number of distinct companies or individuals engaged. The number of producers is difficult to determine, but conservative estimates place it at about 16,000. Some, but not many of this number, have their own pipe lines and refineries and gather their own oil from their leases.

By far the largest part of the so-called "pipe line runs" of the larger companies is, however, oil purchased from a separate producing company or individual. So also with respect to the refineries; some sell their products to more completely equipped companies in "buyer's tank cars." Others, having extensive tank-car holdings, dispose of the product direct to the consumers. Some go still further and maintain retail service stations for the sale of products.

Much has been written of late years concerning our depleted petroleum resources. For several years prior to 1920, the consumption of products exceeded the production of crude oil. The excess was especially great during the war and during the industrial boom immediately succeeding. The resulting high prices of crude oil greatly stimulated exploration work and consequent discoveries of new pools in proven fields and even of oil in entirely new fields. The recent Arkansas development is an example of the latter. Late in 1920 and in 1921, a general depression of industry led to oil production in excess of consumption; with a resulting sharp drop in crude-oil prices. At the present writing, production is starting to decrease as the result of curtailed development work. Unfortunately, the fluctuation

tuations of production follow those of consumption rather tardily. This is on account of the necessity of finishing drilling projects under way. The result is that the production from these projects begins when consumption is already decreasing. On the other hand, when consumption is increasing, there is always delay before new wells can be financed and drilled and production therefrom started.

The last few years have shown that, given the incentive, production can be spurred up to keep pace with consumption for many years to come. Nevertheless, the warnings of competent geologists should be heeded. Various estimates as to oil supply have been advanced; the most reliable, in 1920, placing our reserves underground at about 6,500,000,000 barrels. Since then, several new pools and territories have been proven so that this figure is probably an underestimate.

The program for oil conservation involves well-directed domestic and foreign exploration and development, increased efficiency in refining, and mechanical improvements in the apparatus using petroleum products as fuels or lubricants.

## CHAPTER II

### CRUDE OILS AND THEIR CHARACTERISTICS

It is not the object of this book to discuss in detail all of the many and varied crude oils found in the United States. For complete information, the reader is referred to the bulletins and statistics of the Bureau of Mines, the extensive compilations of Bacon and Hamor, and the information published from time to time in the trade journals. The brief outline submitted in this chapter should, however, be of interest.

The petroleum fields of importance in the United States may be listed as follows:

- |                            |               |
|----------------------------|---------------|
| 1. Appalachian             | 6. Louisiana  |
| 2. Lima-Indiana            | 7. Gulf Coast |
| 3. Illinois                | 8. Wyoming    |
| 4. Midcontinent            | 9. California |
| 5. Central and North Texas |               |

The Appalachian field embraces New York, Pennsylvania, West Virginia, and Tennessee. This field was the first developed in the United States and has long since passed its prime. It is, however, still important; and in 1918 was producing approximately 7 per cent. of the country's crude oil. The Appalachian oil has a paraffine base and a high gravity and has never been equalled from the standpoint of value of products derived therefrom. It is practically free from sulphur and asphalt and presents no difficulties to the refiners. The reputation of Pennsylvania oil for high-grade lubricants is of the best.

The Lima-Indiana field embraces western Ohio and Indiana. While this oil contains only a little asphalt, the high sulphur content necessitates expensive refining methods. For many years it was impossible for Lima oils to compete with the Pennsylvania products on account of the disagreeable odors and poor

burning qualities imparted by their sulphur compounds. Improved refining methods finally overcame the difficulties and enabled the refiners to turn out excellent products.

Illinois crude, while of paraffine base, contains some asphaltic matter. It also contains sulphur, although not to the same large extent as in the Lima-Indiana oils.

The Midcontinent field embraces Oklahoma and Kansas, and the crude therefrom exhibits a wide range of characteristics. In Kansas, considerable sulphur is present in some pools. The crude is of paraffine base with asphaltic matter occasionally present in varying amounts, and is generally of light gravity. That from certain districts, as for example, the pools in Muskogee county, can be treated so as to yield many of the high-grade lubricating stocks. The production of the Oklahoma field, now foremost in the United States, is well established and should show a healthy increase for years to come.

Central and North Texas oils are generally of paraffine base and are low in sulphur. They compare favorably with Midcontinent crudes. Settled production seems questionable, the pools coming in "big" but rapidly falling off. Louisiana crudes from the northern part of the state are similar to those of North Texas. The south Louisiana crudes are usually of asphalt base and are sulphur-bearing. Production is now again increasing after a two years' decline.

Gulf Coast crudes are heavy and of asphalt base. They have varying amounts of sulphur, some of the oils ranging higher in this constituent than the crudes from the Lima-Indiana field. They are, however, more easily treated than the Lima-Indiana crudes.

Wyoming oils are of paraffin base with some asphaltic matter present. Sulphur occurs to a considerable extent in those oils which have a high asphalt content. The production of this field is steadily increasing.

California oils are generally characterized as heavy and asphaltic, although oils of fairly high gravity, and also oils containing paraffine, have been discovered. The pools vary con-

siderably and a general classification would be difficult. The asphalt content is higher than in any other field of this country. Sulphur is present in varying quantities. California is second in production by districts and first by states.

In addition to the above regions, petroleum has been found in Michigan, Arkansas, Alabama, New Mexico, Montana and Alaska, and it is probable that the last five named will in the near future take their places as producing territories.

While the fields may be classified in the above general manner, too much emphasis cannot be placed upon the fact that samples from the same field will often show great variations, and equally wide variations may occur in the products that may be obtained therefrom. For this reason, careful analysis of the crude oil should be conducted by a properly equipped laboratory before it is attempted to design a refinery or to estimate earnings from its operation. A laboratory can forecast results by semi-commercial experiments which will approximate the conditions of actual refinery operation.

The laboratory results which are most necessary in order to permit of designing and forecasting the financial returns from a refinery are the so-called "yield statements" of the crude, together with the usual commercial tests for each of the products. A few typical examples of yields of oils from representative fields are submitted below:

**MUSKOGEE COUNTY, OKLAHOMA: 39°-40° B. GRAVITY**

*Yields by Complete Process*

<i>Per Cent.</i>		<i>Per Cent.</i>	
Gasoline .....	35	Cylinder stocks .....	20
Kerosene ... ..	18	Fuel oil .....	8
Gas Oil .....	8	Wax .....	1
Non-viscous lubricants....	2	Loss .....	4
Viscous lubricants.....	4		

**OKLAHOMA: 34° B. GRAVITY**

*Skimming yields*

<i>Per Cent.</i>		<i>Per Cent.</i>	
Gasoline .....	9.5	Gas oil .....	15.0
Painters' naphtha .. ..	6.2	Fuel oil .....	49.3
Kerosene .....	18.0	Loss .....	2.0

# CRUDE OILS AND THEIR CHARACTERISTICS

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## MIXED SOUTH TEXAS: 22° B. GRAVITY

### Skimming yields

	<i>Per Cent.</i>		<i>Per Cent.</i>
Kerosene .....	5.5	18° fuel oil .....	65.8
Gas oil .....	27.0	Loss .....	1.7

### CORNING

### Skimming yields

	<i>Per Cent.</i>		<i>Per Cent.</i>
Gasoline .....	28	Fuel oil residual .....	45
Kerosene .....	16	Loss .....	2
Gas oil .....	9		

## PENNSYLVANIA: 42° B. GRAVITY

### Yields by Complete Process

	<i>Per Cent.</i>		<i>Per Cent.</i>
Gasoline .....	28	Non viscous neutral.....	6
Turpentine substitute ...	12	Viscous neutral .....	4
Kerosene .....	15	Cylinder stocks .....	15
Mineral seal oil .....	3	Wax .....	2
Gas and fuel oil.....	10	Loss .....	5

## MID-CONTINENT: AVERAGE PIPE LINE RUN

### Yields by Complete Process

	<i>Per Cent.</i>		<i>Per Cent.</i>
Gasoline .....	23	Viscous lubricants .....	6
Kerosene .....	15	Wax .....	1.5
Engine distillate .....	5	Fuel .....	16
Gas oil .....	26	Loss .....	5.5
Non viscous lubricants...	4		

## GOOSE CREEK, TEXAS:

### Yields by Complete Process

	<i>Per Cent.</i>		<i>Per Cent.</i>
Gas oil .....	30	Fuel oil .....	15
Non viscous lubricants ...	14	Loss .....	6
Viscous lubricants .....	35		

## CADDO, LA.: 41°-42° B. GRAVITY

### Yields by Complete Process

	<i>Per Cent.</i>		<i>Per Cent.</i>
Gasoline .....	21	Non viscous lubricants...	5
Naphtha .....	15	Viscous lubricants .....	3
Kerosene .....	28	Wax .....	2
Gas oil .....	10	Fuel oil .....	8
Red oil .....	3	Loss .....	5



## AMERICAN PETROLEUM REFINING

*Skimming yields*

	<i>Per Cent.</i>		<i>Per Cent.</i>
Gasoline .....	20	Fuel oil .....	40.5
Naphtha .....	14	Loss .....	1.5
Kerosene .....	23		

At the present time, many refiners are turning their attention to crude oils brought in from Mexico. A few examples of yields from such crudes follow:

*Panuco oil* is very heavy, 12° to 13° Baume, and of asphalt base, and may be handled as follows:

(1) *Strqight Skimming:*

	<i>Per Cent.</i>		<i>Per Cent.</i>
Gasoline .....	3	Loss .....	1
Residual fuel .....	96		

(2) Run a large cut overhead with consequent cracking (no steam being used) and increased gasoline yield. Blend back the gas oil cut, to decrease the viscosity of the residual fuel. The yields will vary with the viscosity desired for the residual but will lie between the limits given below:

	<i>Per Cent.</i>		<i>Per Cent.</i>
Gasoline .....	5 to 9	Loss .....	1 to 1.5
Residual fuel oil....	94 to 89.5		

## (3) A third method is to reduce the crude to asphalt:

	<i>Per Cent.</i>		<i>Per Cent.</i>
Gasoline .....	5	Asphalt .....	61
Kerosene .....	6	Loss .....	5
Gas oil .....	23		

The *light Mexican* crudes have a mixed base and a greater variety of products is obtainable.

## TUXPAM: 18°-20° B. GRAVITY

*Skimming*

	<i>Per Cent.</i>		<i>Per Cent.</i>
Gasoline .....	12	Fuel oil .....	82
Kerosene .....	5	Loss .....	1

# CRUDE OILS AND THEIR CHARACTERISTICS 9

## *Complete*

<i>Per Cent.</i>	<i>Per Cent.</i>
Gasoline .....15	Heavy lubricants .....10
Kerosene ..... 7	Wax ..... 1
Gas oil .....30	Coke ..... 9
Light lubricants .....22	Loss ..... 6

## *To Asphalt*

<i>Per Cent.</i>	<i>Per Cent.</i>
Gasoline .....12	Asphalt .....45
Kerosene ..... 6	Loss ..... 5
Gas oil .....32	

In connection with all of the typical yields above given, it should be noted that the results obtained in refining will depend upon the method of running, and that the number of methods of running or of combinations of such methods is very great. These yields can therefore be taken only as characteristic, and are subject to some variation.

## CHAPTER III

### CHEMICAL PROPERTIES OF PETROLEUM

By T. T. GRAY AND D. DROGIN

Petroleum is a mixture of chemical compounds of carbon and hydrogen called hydrocarbons, with smaller amounts of sulphur, nitrogen, and oxygen. These last three usually exist as derivatives of the hydrocarbons and are to be regarded as impurities. Hydrogen sulphide, water and earthy matter are often present, in addition.

The elements carbon and hydrogen, of which all hydrocarbons are composed, possess widely different properties. *Carbon* is one of the most widely distributed elements in nature, and is the principal component of all organic compounds. Hydrogen is a colorless, odorless, inflammable gas and is the lightest substance known, being 14.43 times lighter than air. Its density is 0.06947 (air = 1.0).

The *valency* of an element is the combining or saturating capacity of one of its atoms as compared with that of an atom of hydrogen. An atom which will combine with, or replace, one atom of hydrogen is said to be *univalent*. Elements of equal valency combine with each other on the basis of atom for atom. A *bivalent* element requires two univalent atoms for saturation, a *trivalent* requires three, and a *quadrivalent* element requires four univalent atoms.

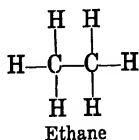
Carbon is a quadrivalent element, and hydrogen is a univalent element. It is evident therefore that one atom of carbon will require four atoms of hydrogen for saturation. Methane,  $\text{CH}_4$ , is a *saturated hydrocarbon*. Its valency is completely satisfied with hydrogen. The carbon atoms have the characteristic of linking themselves together in a greater variety of ways than the atoms of any other elements. These linkages form "open" or "closed" chain compounds. The various groupings of the

atoms are represented by lines called "bonds," so as to indicate the assumed internal arrangement of the atoms in the molecule. Such representations are called "structural formulae."

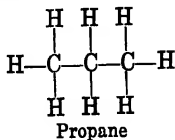
The hydrocarbons may be divided into two general families or series, depending upon their structure. The first are known as the open or straight chain series, sometimes called the *aliphatic group*; and the second series are known as the closed chain or ring compounds, constituting the *aromatic group*. The open chain may be written in a straight line with each carbon atom united to one or more additional carbon atoms; the additional or unsatisfied valences are satisfied by atoms of hydrogen, or by additional bonds uniting two carbon atoms. In the closed chain or ring series, the atoms of carbon are arranged in a circular structure, in which each carbon atom is united with a definite number of hydrogen atoms. Graphic illustrations will make the distinction clear.

As a representative of the aliphatic series we may consider ethane, which is the second member of that class of hydrocarbons known as paraffins.

Ethane has the formula  $C_2H_6$ , which may be also written in the following manner, constituting what is known as a graphic or structural formula:

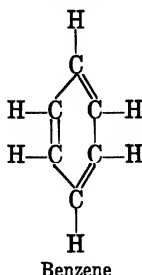


Propane ( $C_3H_8$ ) may also serve as an example of a member of the straight chain series:



In the above formula, the carbon atoms at the end of the chain are united with more atoms of hydrogen than the carbon atoms at or near the center of the chain.

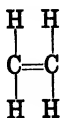
Benzene, ( $C_6H_6$ ) may serve as an illustration of the closed chain or ring compounds; its structure being as follows:



Each carbon atom in this ring is united with a single hydrogen atom, which may be replaced by other atoms or groups. All "aromatic compounds" must contain this ring in some combination or other.

When, as above, the valence of all the carbon atoms of a compound is not completely satisfied by atoms of hydrogen, the compound is *unsaturated*. To satisfy the valence of the carbon atoms which would ordinarily be satisfied by hydrogen atoms, we have put additional bonds of union between the carbon atoms wherever necessary. Saturated compounds contain carbon atoms which are united to each other by a single bond of union, the additional bonds being occupied by hydrogen. The carbon atoms of unsaturated compounds are united to each other by double or triple bonds of union, according to the number of hydrogen atoms absent. No two carbon atoms can be united to each other by four bonds of union. Examples of unsaturated hydrocarbons are as follows:

Ethylene,  $C_2H_4$ :

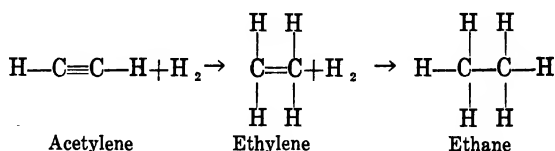


Acetylene,  $C_2H_2$ :



Ethylene contains a double bond, and acetylene a triple bond of union.

The molecule of an unsaturated hydrocarbon is more unstable than the corresponding saturated molecule containing singly linked atoms. One or two of the unsaturated bonds may be satisfied by additional hydrogen atoms, so as to produce saturated compounds. The process of transforming double or triple bonds into single bonds by the addition of hydrogen is known as hydrogenation, and finds wide application in the industries. This process can be illustrated by the following equation:



Thus, the doubly bonded compound ethylene may be transformed into the singly bonded or saturated ethane, or may be produced from the triply bonded acetylene by the addition of hydrogen. Hydrogenation always transforms unsaturated compounds into compounds containing two more hydrogen atoms to the molecule, than the preceding compound. Hydrogen is always added two atoms at a time, never in single atoms.

Each family of hydrocarbons is represented by a general chemical formula. The following table gives a list of the series which are important in petroleum chemistry:

TABLE 1

Name of Series	General Formula
Methane, or Paraffine .....	$\text{C}_n \text{H}_{2n+2}$
Ethylene, or Olefine .....	$\text{C}_n \text{H}_{2n}$
Acetylene .....	$\text{C}_n \text{H}_{2n-2}$
Diolefine .....	$\text{C}_n \text{H}_{2n-2}$
Olefinacetylene .....	$\text{C}_n \text{H}_{2n-4}$
Olefineterpene .....	$\text{C}_n \text{H}_{2n-4}$
Benzene .....	$\text{C}_n \text{H}_{2n-6}$
Naphthene, Cycloparaffine or Polymethylene.....	$\text{C}_n \text{H}_{2n-4} \text{H}_6$
.....	$\text{C}_n \text{H}_{2n-6} \text{ up to—}$
.....	$\text{C}_n \text{H}_{2n-8}$

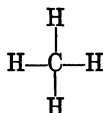
TABLE 2: PARAFFIN SERIES  $C_n H_{2n+2}$ 

Name	Conventional Formula	Specific Gravity	Melting Point, °C.	Boiling Point, °C.
Methane	CH <sub>4</sub>	0.415 <sup>a</sup>	-184	-164
Ethane	C <sub>2</sub> H <sub>6</sub>	0.446	-172.1	-84.1 <sup>f</sup>
Propane	C <sub>3</sub> H <sub>8</sub>	0.536	-45	-37
Normal butane	C <sub>4</sub> H <sub>10</sub>	0.6 <sup>a</sup>	-135.3 <sup>1</sup>	1
Iso butane	do.	0.6029	—	-17
Normal pentane	C <sub>5</sub> H <sub>12</sub>	0.6454	-130.8 <sup>1</sup>	36.3
Iso pentane	do.	0.6393	—	30.4
Neo pentane	do.	—	-20	9
Normal hexane	C <sub>6</sub> H <sub>14</sub>	0.6603 <sup>c</sup>	-94.03 <sup>1</sup>	68.9
Methyl diethyl methane	do.	0.6765 <sup>d</sup>	—	64
Di-methyl propyl methane	do.	0.6766	—	62
Di-iso propyl	do.	0.668 <sup>e</sup>	—	58
Tri-methyl ethyl methane	do.	0.6488 <sup>c</sup>	—	49.5
Neo heptane	C <sub>7</sub> H <sub>16</sub>	0.70186	-97.1 <sup>1</sup>	98.3
Iso 2 methyl hexane	do.	0.7067	—	89.9-90.4
Tetra-methyl propane	do.	0.6971	—	83-84
Tri-methyl propyl methane	do.	—	—	78.5-79.0
Di-methyl di-ethyl methane	do.	—	—	89.5-90.0
Normal octane	C <sub>8</sub> H <sub>18</sub>	0.7188	—	125.8
2-methyl heptane	do.	—	—	116 <sup>2</sup>
3- do. do.	do.	—	—	117.6 <sup>2</sup>
4- do. do.	do.	—	—	118 <sup>2</sup>
2 : 5 di-methyl hexane	do.	0.7111	—	108.3 <sup>2</sup>
2 : 2 <sup>1</sup> : 3 : 3 <sup>1</sup> tetra-methyl butane	do.	—	—	104 <sup>2</sup>
Normal nonane	C <sub>9</sub> H <sub>20</sub>	0.7177 <sup>c</sup>	-51	150.8
Normal decane	C <sub>10</sub> H <sub>22</sub>	0.7467 <sup>c</sup>	-31	173
Iso decane (di iso amyl)	do.	0.7479 <sup>c</sup>	—	163
Endecane	C <sub>11</sub> H <sub>24</sub>	0.7581 <sup>c</sup>	-26.5	196-197
Dodecane	C <sub>12</sub> H <sub>26</sub>	0.7676 <sup>c</sup>	-12	214-216
Tridecane	C <sub>13</sub> H <sub>28</sub>	0.775 <sup>c</sup>	-6	234
Tetra decane	C <sub>14</sub> H <sub>30</sub>	0.775 <sup>c</sup>	4	252
Pentadecane	C <sub>15</sub> H <sub>32</sub>	0.776 <sup>c</sup>	10	270
Hexadecane	C <sub>16</sub> H <sub>34</sub>	0.775 <sup>c</sup>	18	287
Heptadecane	C <sub>17</sub> H <sub>36</sub>	0.777 <sup>c</sup>	22	303
Octadecane	C <sub>18</sub> H <sub>38</sub>	0.777 <sup>c</sup>	28	317
Nonadecane	C <sub>19</sub> H <sub>40</sub>	0.777 <sup>c</sup>	32	330
Eicosane	C <sub>20</sub> H <sub>42</sub>	0.778 <sup>c</sup>	37	205 <sup>A</sup>
Heneicosane	C <sub>21</sub> H <sub>44</sub>	0.778 <sup>c</sup>	40	215 <sup>A</sup>
Docosane	C <sub>22</sub> H <sub>46</sub>	0.778 <sup>c</sup>	44	224 <sup>A</sup>
Tricosane	C <sub>23</sub> H <sub>48</sub>	0.779 <sup>c</sup>	48	234 <sup>A</sup>
Tetracosane	C <sub>24</sub> H <sub>50</sub>	0.779 <sup>c</sup>	51	243 <sup>A</sup>
Pentacosane	C <sub>25</sub> H <sub>52</sub>	—	53.5	—
Hexacosane	C <sub>26</sub> H <sub>54</sub>	—	58	—
Heptacosane	C <sub>27</sub> H <sub>56</sub>	0.780 <sup>c</sup>	60	270 <sup>A</sup>
Octacosane	C <sub>28</sub> H <sub>58</sub>	—	60	—
Nonacosane	C <sub>29</sub> H <sub>60</sub>	—	62.5	—
(Ceryl)	C <sub>30</sub> H <sub>62</sub>	—	—	370 <sup>B</sup>
Hentriacontane	C <sub>31</sub> H <sub>64</sub>	0.781 <sup>c</sup>	68	302 <sup>A</sup>
Dotriacontane	C <sub>32</sub> H <sub>66</sub>	0.781 <sup>c</sup>	70	310 <sup>A</sup>
Tettriacontane	C <sub>33</sub> H <sub>68</sub>	—	71.5	—
Pentatriacontane	C <sub>34</sub> H <sub>70</sub>	—	75	331
Hexacontane	C <sub>35</sub> H <sub>72</sub>	0.782 <sup>c</sup>	—	—
(Dimiricyl)	C <sub>60</sub> H <sub>122</sub>	—	102 <sup>A</sup>	—

(Engler-Höfer; Meyer and Jacobson, Lehr. d. Org. Chem., 2d. Ed., I.)

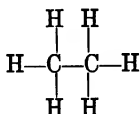
METHANE, OR PARAFFINE SERIES:  $C_n H_{2n+2}$ :

Table 2 gives some of the properties of members of the first of these series in detail. Most of the compounds are liquid at ordinary temperatures, but  $CH_4$ ,  $C_2H_6$ ,  $C_3H_8$ ,  $C_4H_{10}$  and neopentane are gases and the heavy members from  $C_{10}H_{22}$  on are solids. Specific gravities are at 0° C. unless otherwise stated. The members of this group (the methane or paraffin series) are composed of saturated hydrocarbons, i.e., hydrocarbons containing singly linked carbon atoms only. The simplest member is the gas, methane,  $CH_4$ . One molecule of methane contains four atoms of hydrogen linked to one atom of carbon, thus:



The composition by weight is 75 parts of carbon to 25 of hydrogen.

The next member of this series is ethane,  $C_2H_6$ , which has the structure:



In this compound, the carbon atoms are linked by a common bond, and each carbon atom has four single bonds. Ethane con-

<sup>a</sup> At the boiling point.

<sup>b</sup> As liquid.

<sup>c</sup> At 20° C.

<sup>d</sup> At 20.5° C.

<sup>e</sup> At 17.5° C.

<sup>f</sup> At 749 mm. pressure.

<sup>g</sup> At the melting point.

<sup>h</sup> At 15 mm. pressure.

<sup>1</sup> Holleman, Org. Chem., 41 (1915).

<sup>2</sup> Ibid., 48.

<sup>3</sup> Redwood, Treatise on Petroleum, 1, 242 (1913).

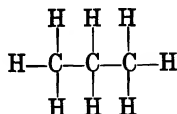
<sup>4</sup> Richter, Org. Chem., 1, 86 (1899).

*These notes refer to  
Table 2, page 14.*



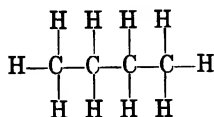
tains 80 per cent. of carbon by weight. The next four members of this series, together with their isomers, are represented below:

Propane,  $C_3H_8$ :

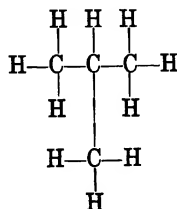


Only one compound having the formula  $CH_4$  is known. There are only single examples, also, of the compounds  $C_2H_6$  and  $C_3H_8$ . With  $C_4H_{10}$ , two compounds are known; both containing 82.8 per cent. by weight of carbon:

Normal Butane

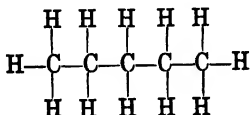


Iso Butane

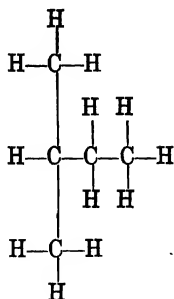


There are three pentanes  $C_5H_{12}$ , each consisting of 83.33 per cent. carbon and 16.67 per cent. hydrogen.

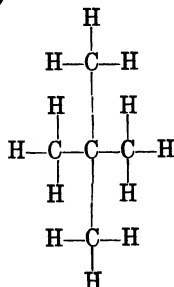
Normal Pentane



Iso Pentane or Dimethylethylmethane

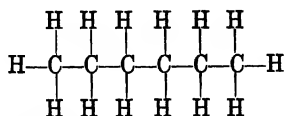


Tertiary Pentane (or  
Tetramethylmethane)

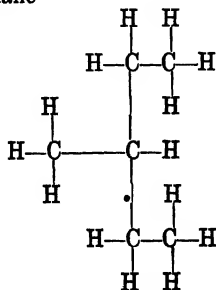


There are five hexanes,  $\text{C}_6\text{H}_{14}$ , consisting of carbon 83.72 and hydrogen 16.28 per cent.:

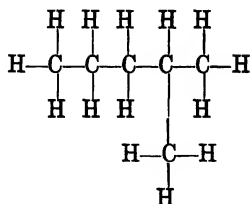
Normal Hexane



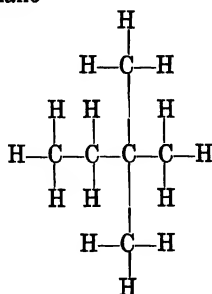
Methyldiethylmethane



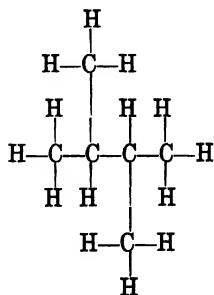
## Dimethylpropylmethane



## Trimethylethylmethane



## Di-isopropyl



The number of possible isomers (isomerides) increases rapidly as the number of carbon atoms increase in the molecule; mathematically, 802 compounds of the formula  $\text{C}_{18}\text{H}_{38}$  would be possible.

The isomerides are classified as normal or primary, iso or secondary, and tertiary, according to their molecular arrangement.

A normal hydrocarbon is one in which no carbon atom is united with more than two others. A secondary hydrocarbon contains a carbon atom combined with three others directly, and a tertiary hydrocarbon is one in which one carbon atom is combined with four others. The first of the hexanes listed above is a normal compound. Methyldiethylmethane is a secondary isomer, and trimethylethylmethane is a tertiary hydrocarbon.

The members of this series are all lighter than water. The specific gravities increase with the molecular weights. The specific gravities of the higher members at the melting points are almost the same; they rise from 0.758 for tridecane ( $C_{13}H_{28}$ ) to 0.782 for pentatriacontane ( $C_{36}H_{72}$ ); consequently the molecular volumes are nearly proportional to the molecular weights<sup>1</sup> at the boiling points. All of these compounds are insoluble in water; the lower ones are readily soluble in alcohol and ether.

The boiling points rise with the molecular weights. The highest members are not volatile without decomposition except under reduced pressure.

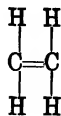
The hydrocarbons of the paraffin series are stable compounds; they are not attacked under normal conditions by oxidizing agents; they resist the action of strong alkalies. The normal members are not absorbed by sulphuric acid. With the halogens (chlorine and bromine), in the sunlight, they yield substitution products. Iodine has no action on the paraffins.

#### OLEFINE OR ETHYLENE SERIES, $C_n H_{2n}$

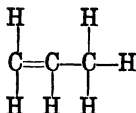
Varying proportions of hydrocarbons of the ethylene or olefine series,  $C_n H_{2n}$ , are found in most crude oils. These hydrocarbons contain two hydrogen atoms less than the corresponding paraffin hydrocarbons. Each olefine hydrocarbon contains two adjacent carbon atoms doubly linked. The structural formula of ethylene, the simplest olefine, and also those of propylene and butylene (with its isomers) are shown herewith:

<sup>1</sup> F. Krafft, Ber. d. d. Chem. Ges., 15, 1711 (1882).

Ethylene,  $C_2H_4$ :

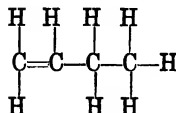


Propylene,  $C_3H_6$ :

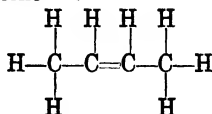


Butylene,  $C_4H_8$ :

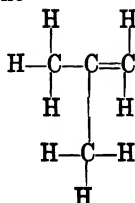
Normal or  
 $\alpha$ -butylene



$\beta$ -butylene



Iso or  
 $\gamma$ -butylene



While the paraffin series is composed of hydrocarbons which contain singly linked carbon atoms only, and are therefore saturated hydrocarbons, the hydrocarbons of the olefine group are unsaturated. Table 3 lists members of this series.

In physical properties, the olefines resemble the paraffin hydrocarbons; the first four members are gases; those following, up to and including pentadecylene ( $C_{15}H_{30}$ ), are liquids; and those below are solids. Generally, their boiling points are a few degrees higher than those of the corresponding paraffins. They are insoluble in water and soluble in alcohol, and are lighter than water.

Chemically, they differ greatly from the members of the par-

affin series, because of the double linkage between the carbon atoms. Being unsaturated, they are capable of taking up more hydrogen, or of combining with other elements or compounds, so as to convert the double bond of the carbon atom into a single linkage.

TABLE 3. ETHYLENE SERIES,  $C_nH_{2n}$

Name	Formula	Specific Gravity	Melting Point, °C.	Boiling Point, °C.
Ethylene	$C_2H_4$	0.6095 (liq.)	-169	-102.7 at 757 mm.
Propylene	$C_3H_6$	—	—	- 48.2 at 749 mm.
Ethyl ethylene (butene)	$C_4H_8$	—	—	-5
Iso butylene	do.	—	—	-6
Symm. dimethyl ethylene	do.	—	—	1
N. propyl ethylene (amylene)	$C_5H_{10}$	—	—	39-40
Iso propyl ethylene	do.	0.648 at 0°	—	20-21
Symm. methyl ethyl ethylene	do.	—	—	36
Unsymm. meth. eth. ethylene	do.	0.670 at 0°	—	31-32
Tri methyl ethylene	do.	0.685 at 0°	—	36
N-hexylene	$C_6H_{12}$	0.683 at 15°	—	68-70
Tetra methyl ethylene	do.	0.7006 at 19°	—	72
Heptylene	$C_7H_{14}$	0.703 at 19.5°	—	95
Octylene	$C_8H_{16}$	0.722 at 17°	—	122-123
Nonylene	$C_9H_{18}$	—	—	153 <sup>1</sup>
Decylene	$C_{10}H_{20}$	0.7512 at 15°	—	172
Undecylene	$C_{11}H_{22}$	—	—	195 <sup>1</sup>
Dodecylene	$C_{12}H_{24}$	0.795 at melting point	- 31	96 at 15 mm.
Tridecylene	$C_{13}H_{26}$	0.8087 at 20°	—	228-230 <sup>2</sup>
Tetradecylene	$C_{14}H_{28}$	0.794 at melting point	- 12	127 at 15 mm.
Penta decylene	$C_{15}H_{30}$	0.8192 at 20°	—	159-169 at 50 mm.
Hexadecylene	$C_{16}H_{32}$	0.792 at melting point	+ 4	155 at 15 mm.
Octa decylene	$C_{18}H_{36}$	0.791 at melting point	18	179 at 15 mm.
Eicosylene	$C_{20}H_{40}$	0.8181 at 24°	—	314-315
—	$C_{22}H_{44}$	—	—	258-260 <sup>2</sup>
—	$C_{24}H_{48}$	—	—	272-274 <sup>1</sup>
Cerotene	$C_{27}H_{54}$	—	58	—
Melene	$C_{30}H_{60}$	—	62	—

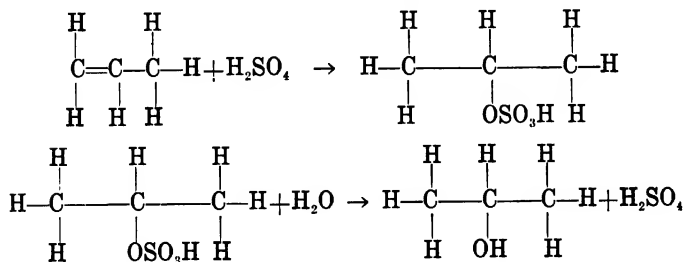
(Engler-Höfer: Meyer-Jacobson, op. cit.)

<sup>1</sup> Holleman, op. cit., 48.

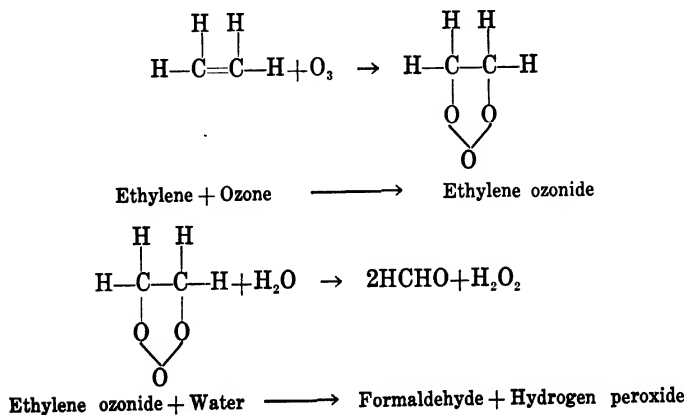
<sup>2</sup> Redwood, op cit., 244.

Sulphuric acid absorbs some of these compounds and polymerizes others. The absorbed olefines are converted into ethe-

real salts; a reaction which can be used as a preliminary to the formation of alcohols. For example, propylene, when treated with sulphuric acid and then water, yields isopropyl alcohol:



The polymerization of olefines by sulphuric acid accounts for the increase in viscosity sometimes observed in lubricating oils after their treatment with sulphuric acid. Potassium permanganate converts olefines into glycols. More complete oxidation severs the double bond; ozone ( $\text{O}_3$ ) reacts to form ozonides, which are decomposed by water into two molecules of aldehydes or ketones:



This reaction is used to locate the presence, and sometimes the position, of a double bond.

ACETYLENE GROUP,  $C_n H_{2n-2}$ 

The acetylene hydrocarbons contain carbon atoms which are triply united. They are isomeric with diolefines, which contain two double bonds.

Small quantities of hydrocarbons of the acetylene group,  $C_n H_{2n-2}$ , occur in Baku oil. The members of this series contain two less hydrogen atoms than the corresponding compounds of the ethylene series. Being more highly unsaturated, the members of the acetylene group show a greater chemical activity.

A characteristic reaction of the acetylenes is their property of yielding crystalline compounds with ammoniacal solutions of silver or copper salts. Some of the acetylenes are absorbed by sulphuric acid, while others are polymerized to compounds of ring formation.

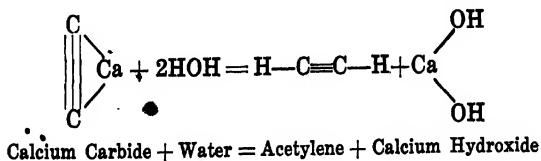
Acetylene hydrocarbons combine with hydrogen to form olefines, which, in turn, by further hydrogenation, are converted into paraffins.

TABLE 4. ACETYLENE SERIES,  $C_n H_{2n-2}$ 

	Name	Formula	Melting Point, °C.	Boiling Point, °C.
	Acetylene	$HC \equiv CH$	-81.5	-83.6
	Allylene (propine)	$HC \equiv C.CH_3$	-110	-23.5
	Crotonylene	$CH_3.C \equiv C.CH_3$		27
	Ethyl acetylene (butine)	$HC \equiv C.C_2H_5$		18
(3-pentine)	Methyl ethyl acetylene	$CH_3.C \equiv C.C_2H_5$		55
(pentine) . . .	n-propyl acetylene	$HC \equiv C.CH_2.CH_2.CH_3$		48
	iso propyl acetylene	$HC \equiv C-CH(CH_3)_2$		28
	methyl n-prop. acetylene	$CH_3.C \equiv C.C_3H_7$		84

(The first two are gases: the remaining members are liquids.)

Berthélot prepared acetylene synthetically by passing an electric spark between carbon points in an atmosphere of hydrogen; small quantities of methane and ethane were also produced. Acetylene may be formed also from calcium carbide:





Acetylene is formed as the result of decomposition when methane, ethylene, and other hydrocarbons are heated to high temperatures.

The hydrocarbons of the acetylene series up to  $C_{12}H_{22}$  are sparingly soluble in water and much more readily soluble in alcohol. They are capable of forming copper and silver salts, which are explosive.

#### DIOLEFINE SERIES, $C_n H_{2n-2}$

TABLE 5. DIOLEFINE SERIES,  $C_n H_{2n-2}$

(Engler-Höfer: Das Erdöl, 1, 338)

Name	Formula	Boiling Point, °C
Allene	$CH_2=C=CH_2$	—
Divinyl	$CH_2=CH-CH=CH_2$	1
Piperylene	$CH_2=CH.CH=CH.CH_2$	42
Isoprene	$CH_2=CH.C(CH_3)=CH_2$	35
Diisopropenyl	$CH_2=C(CH_3).C(CH_3)=CH_2$	71
1, 1, 3-trimethyl butadiene	$(CH_3)_2C=CH.C(CH_3)=CH_2$	93
Diallyl	$CH_2=CH.CH_2.CH=CH_2$	59
2-5-dimeth. 1-5 hexadiene	$CH_2=C(CH_3).CH_2.CH_2.C(CH_3)=CH_2$	137
1, 1, 5-trimeth. 1-5 hexadiene	$(CH_3)_2C=CH.CH_2.CH_2.C(CH_3)=CH_2$	141
Conylene	$CH_2=CH.CH_2.CH=CH.CH_2.CH_2.CH_2$	126

(The first is a gas: the others are liquids)

The hydrocarbons of this series are isomeric with the acetylenes. They contain the same number of hydrogen atoms, but the unsaturation is due in their case to the presence of two double-bonded carbon atoms instead of one triple-bonded carbon atom, as with acetylene. The diolefine allene of Table 5 is isomeric with allylene of Table 4. The diolefines do not form silver or copper salts with ammoniacal solutions of these metals. With mercuric sulphate and chloride in aqueous solution, they form precipitates.

Ozone unites with diolefines, forming diozonides, which can be decomposed by water. Sulphuric acid causes polymerization of the diolefines, with the formation of tarry substances.

The diolefine hydrocarbons undoubtedly cause the petroleum refiner more annoyance than any of the other groups of hydrocarbons of which petroleum and its products are composed. Members of this series polymerize readily, with a consequent

darkening of the product containing them. Diolefines are produced in relatively large quantities by some of the present methods of cracking gas oils to produce gasoline.

Members of this series have been found in Texas, Ohio and California crude oil.

#### OLEFINEACETYLENE SERIES

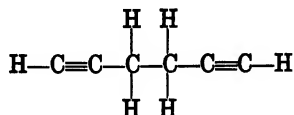
In the olefinacetylene series are hydrocarbons of the general formula  $C_nH_{2n-4}$ . These members contain both double- and triple-linked carbon atoms in their molecules.

#### OLEFINE TERPENES, $C_nH_{2n-4}$

Another series of hydrocarbons includes the olefine terpenes. Hydrocarbons having the same general formula as this group have been found in Canadian,<sup>1</sup> Texas,<sup>2</sup> and Caucasian<sup>3</sup> petroleum. Myocene ( $C_{10}H_{16}$ ), sp. gr. = 0.8025 at 15° C.; index of refraction = 1.4673;<sup>4</sup> and anhydrogeraniol ( $C_{10}H_{16}$ ) boiling point 172–175° C., sp. gr. = 0.8232 at 20° C., index of refraction 1.4835; are members of this series. The olefine terpenes are straight chain compounds. They are not true terpenes, which latter are ring compounds.

#### DIACETYLENES SERIES, $C_nH_{2n-6}$

These hydrocarbons are isomeric with the benzene series. They contain two triple-bonded carbon atoms. Diacetylene ( $H-C\equiv C-C\equiv C-H$ ) is a gas which gives a yellow precipitate with an ammoniacal silver solution. Dipropargyl,



is a liquid of penetrating odor, boiling at 85° C. It forms copper and silver salts and polymerizes readily on standing.

<sup>1</sup> Mabery, Proc. Amer. Philos. Soc., 42, 36 (1903); J. Amer. Chem. Soc., 22, 558 (1900).

<sup>2</sup> Thiele, Chem. Central Blatt., 761, 1901.

<sup>3</sup> Markownikoff-Ogioblin, Berl. Berichte., 16, 1873 (1883).

<sup>4</sup> Richter, op. cit., 2, 309.

TRIOLEFINES,  $C_n H_{2n-6}$ 

Another series of the aliphatic or straight-chain groups, isomeric with the diacetylenes and benzenes, are the triolefine hydrocarbons, which contain three double-bonded carbon atoms.

BENZENE SERIES,  $C_n H_{2n-6}$ TABLE 6. BENZENE SERIES,  $C_n H_{2n-6}$ 

(Engler-Höfer: K. von Auwers Ann., 419, 92-120 (1919).)

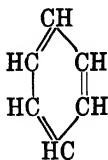
Name	Conventional Formula	Structural Formula	Specific Gravity	Melting Point, °C.	Boiling Point, °C.
Benzene.....	$C_6H_6$	$C_6H_6$	0.8785	5.4	80.4
Toluene.....	$C_7H_8$	$C_6H_5.CH_3$	0.869 at 16°	97-99	110.3
Ortho xylene...	$C_8H_{10}$	$C_6H_4.(CH_3)_2$ 1.2	0.880	-28	142
Meta xylene..	$C_8H_{10}$	$C_6H_4.(CH_3)_2$ 1.3	0.881 at 0°	-53	138.9
Para xylene..	$C_8H_{10}$	$C_6H_4.(CH_3)_2$ 1.4	0.880 at 0°	3	138
Ethyl benzene	$C_8H_{10}$	$C_6H_5.C_2H_5$	0.866	—	135-136
Mesitylene...	$C_9H_{12}$	$C_6H_3.(CH_3)_3$ 1, 3, 5	0.865 at 14°	-57.5	164.5
Pseudo cumene	"	$C_6H_3.(CH_3)_3$ 1, 2, 4	0.895 at 0°	—	169.8
Trimethylbenzene.....	"	$C_6H_3.(CH_3)_3$ 1, 2, 3	—	—	175
Ethyl toluene o.....	"	$C_6H_4.C_2H_5.CH_3$ 1.2	0.881	—	164.8-165
Ethyl toluene m.....	"	$C_6H_4.C_2H_5.CH_3$ 1.3	0.867	—	161.5-162.5
Ethyl toluene p.....	"	$C_6H_4.C_2H_5.CH_3$ 1.4	0.862	—	161.2
O. methyl propyl benzene	$C_{10}H_{14}$	$C_6H_5.CH_2.CH_2.CH_3$	0.874	—	184
M. methyl propyl benzene	"	"	0.862	—	181.5-182.5
P. methyl propyl benzene	"	"	0.861	—	182-183
O. cymene...	"	$C_6H_4.CH_3.C_3H_7$	0.876	-73.5	175-176
M. cymene...	"	"	0.860	—	175
Diethyl benzene.....	"	$C_6H_4.C_2H_5.C_2H_5$ p.	0.865	—	183
Durol.....	"	$C_6H_3.(CH_3)_4$ 1, 2, 4, 5	0.901	79	203-204
Iso durol.....	"	$C_6H_3.(CH_3)_4$ 1, 2, 3, 5	—	—	195-197
Penta methylbenzene.....	$C_{11}H_{16}$	$C_6H_4.(CH_3)_5$	—	53	230
Diethyl toluene.....	"	$C_6H_3.(C_2H_5)_2$ 1.5, (CH <sub>3</sub> )	—	—	198-200
Isoamyl benzene.....	"	$C_6H_5.C_5H_{11}$	0.835 at 18°	—	194
Hexa methyl benzene.....	$C_{12}H_{18}$	$C_6(CH_3)_6$	—	164	264
Penta ethyl benzene....	$C_{16}H_{26}$	$C_6H(C_2H_5)_5$	0.8985 at 19°	—	277
Hexa ethyl benzene....	$C_{18}H_{30}$	$C_6(C_2H_5)_6$	—	129	298

The hydrocarbons previously described consist of open car-

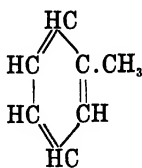
bon chains, and are known as aliphatic hydrocarbons. We now come to the closed rings of carbon atoms, forming what are known as aromatic or carboxylic compounds. These compounds contain from three to seven carbon atoms in the ring. Benzene is the parent hydrocarbon of the aromatic group. Specific gravities in Table 6 are at 20° C., unless otherwise specified.

The aromatic hydrocarbons belonging to the series  $C_nH_{2n-6}$ , and their derivatives, are found in most crude oils. All of these hydrocarbons contain in their molecules a closed chain or nucleus of carbon atoms. The graphic formula of the simplest of these hydrocarbons, benzene, and those of some of its homologues, are as follows:

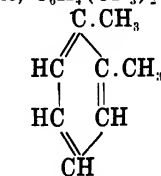
Benzene,  $C_6H_6$ :



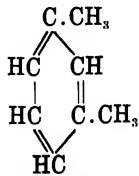
Toluene,  $C_6H_5CH_3$ :



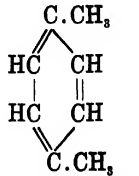
Xylene,  $C_6H_4(CH_3)_2$ :



Ortho-xylene



Meta-xylene



Para-xylene

The stability of the benzene nucleus distinguishes the aromatic hydrocarbons from compounds of the methane series. A large number of hydrocarbon derivatives may be formed by the replacement of one or more of the hydrogen atoms by radicals. The aromatic compounds yield nitro derivatives when treated with nitric acid, and sulphonic acids when concentrated sulphuric acid is added.

NAPHTHENES OR CYCLOPARAFFINS,  $C_n H_{2n-6} + H_2$ TABLE 7: NAPHTHENE SERIES,  $C_n H_{2n-6} + H_2$ 

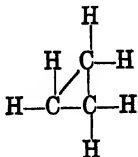
Name	Formula	Melting Point, °C.	Boiling Point, °C.	Specific Gravity	Index of Refraction
Cyclo propane.....	$C_3H_6$	-126	-35	—	—
Methyl cyclo propane..	$C_4H_8$	—	4-5	0.6912 at 20°	—
Cyclo butane.....	"	- 80	11-12	0.7038 at 0°	—
Methyl cyclo butane...	$C_5H_{10}$	—	39-42	—	—
Di methyl 1, 1, cyclo propane.....	"	—	21	0.6604	—
Cyclo pentane.....	"	- 80	50.25-50.75	0.7635 at 0°	—
Tri-methyl 1, 1, 2-cyclo-propane.....	$C_6H_{12}$	—	56-57 at 750 mm.	0.6822 at 19.5°	1.3848 at 19.5°
Tri-methyl 1, 2, 3-cyclo-propane.....	"	—	65-66 at 748 mm.	0.6921 at 22°	1.3942
Ethyl cyclo butane....	"	—	72.2-72.5	0.745 at 20°	1.408 at 19.5°
Methyl cyclo pentane..	"	—	72-72.2	—	—
Cyclo hexane.....	"	6.4	80.8-80.9	0.7788 at 19.5°	1.4277
Di methyl 1, 1, cyclo pentane.....	$C_7H_{14}$	—	87.8-87.9	0.7547 at 20°	1.4131
Di methyl 1, 2, cyclo pentane.....	"	—	92.7-93	0.7534 at 20°	1.4126 at 20°
Di methyl 1, 3, cyclo pentane.....	"	—	91-91.5	0.7543 at 20°	—
Methyl hexane.....	"	—	100.2 at 751 mm.	0.7697 at 20°	—
Cyclo heptane.....	"	—	117-117.5 at 763 mm.	0.816 at 15°	—
Methyl 1, ethyl 2, cyclo-pentane.....	$C_8H_{16}$	—	124	—	—
Methyl 1, ethyl 3, cyclo-pentane.....	"	—	120.5-121 at 751 mm.	0.7669 at 16°	1.4214 at 16°
Di methyl 1, 1, cyclo hexane.....	$C_8H_{16}$	—	117 at 743 mm.	—	—
Di methyl 1, 2, cyclo hexane.....	"	—	126	0.7681 at 20°	—
Di methyl 1, 3, cyclo hexane.....	"	—	118	0.7736 at 18°	1.42558 at 20°
Di methyl 1, 4, cyclo hexane.....	"	—	120	0.7690 at 20°	1.4244 at 20°
Ethyl cyclo hexane....	"	—	130	0.8025 at 0°	—
Cyclo octane.....	"	11.5	147.3-148.3	0.850 at 0°	1.45777 at 16°
Cyclo-butyl di ethyl methane.....	$C_8H_{18}$	—	151-154	0.7946 at 19°	1.4334
Tri methyl 1, 1, 3-cyclo hexane.....	"	—	137-138	0.7848 at 15°	1.4324
Tri methyl 1, 2, 4-cyclo hexane.....	"	—	143-144	0.8052 at 0°	—
Tri methyl 1, 3, 4-cyclo hexane.....	"	—	139-140	0.789 at 20°	1.4630 at 20°

TABLE 7—*Continued*

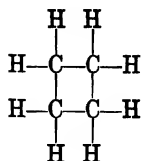
Name	Formula	Melting Point, °C.	Boiling Point, °C.	Specific Gravity	Index of Refraction
Tri methyl 1, 3, 5-cyclohexane . . . . .	"	—	137-139	0.7884 at 0°	—
Methyl 1, ethyl 2, cyclohexane . . . . .	"	—	150-152	—	—
Methyl 1, ethyl 3, cyclohexane . . . . .	"	—	149-150	0.7989 at 20°	—
Methyl 1, ethyl 4, cyclohexane . . . . .	"	—	150	0.8041 at 0°	—
Propyl cyclo hexane . . . . .	"	—	153-154	0.8091 at 0°	—
Iso " " " . . . . .	"	—	146	0.812 at 0°	—
Ethyl cyclo heptane . . . . .	"	—	163-163.5	0.8152 at 20°	—
Di methyl 1, 2, cyclo heptane (?) . . . . .	"	—	150-152	—	—
Cyclo nonane . . . . .	"	—	170-172	0.7733 at 16°	1.4328 at 16°
Methyl 1, isopropyl 4, cyclo hexane . . . . .	C <sub>10</sub> H <sub>20</sub>	—	169-170	0.8132 at 0°	—
Di-ethyl 1, 3, cyclo hexane . . . . .	"	—	169-171	0.7957 at 22°	—
Methyl 1, ethyl 3 iso propyl 4, cyclo hexane . . . . .	C <sub>12</sub> H <sub>24</sub>	—	207-208 at 736 mm.	0.8146 at 20°	—
Di methyl 1, 3, iso butyl hexane . . . . .	"	—	193-195	0.8227 at 0°	—

(Engler-Höfer: Skowronski-Metan; 61, 73, 86, 97, 109, (1918).)

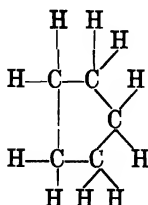
Hydroaromatic hydrocarbons of this series are probably present to some extent in all petroleum. They form a large part of Russian crude oil; they occur in small amounts in the light Appalachian oils, and in larger proportions in the heavy sulphur and asphaltic varieties<sup>1</sup> of petroleum. These hydrocarbons are called naphthenes. They are isomeric with the olefines (C<sub>n</sub>H<sub>2n</sub>), but are of ring formation. The graphic formulae of a few members of the naphthene series are as follows:

Cyclo-propane, C<sub>3</sub>H<sub>6</sub>:<sup>1</sup> Mabery, Mining and Metallurgy, 158; Sec. 34.

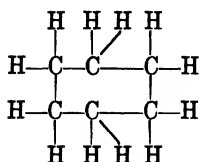
Cyclo-butane,  $C_4H_8$ :



Cyclo-pentane,  $C_5H_{10}$ :

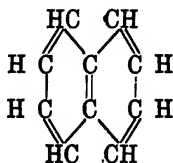


Cyclo-hexane,  $C_6H_{12}$ :



The naphthenes closely resemble the paraffins in physical and chemical properties. They are much more stable than the olefines. The specific gravities of the different members are higher than those of the corresponding olefine isomers.

Hydrocarbons and their homologues, belonging to this series, have been found in Borneo crude<sup>1</sup> and in California (Puente) crude.<sup>2</sup> The simplest member of this family is naphthalene,  $C_{10}H_8$ . Its graphic formula is:



<sup>1</sup> St. Claire-De Ville, Lit.-Zitate u. weit. Sauerstoffgehalte S. bei Element. Zu samm. d. Roherdöle, 220.

<sup>2</sup> Jones & Wootton, J. Chem. Soc. Trans., 2, 1149 (1907).

## NAPHTHALENE GROUP

TABLE 8: NAPHTHALENE SERIES

Name	Formula	Melting Point, °C.	Boiling Point, °C.
Naphthalene.....	$C_{10}H_8$	79	218
$\alpha$ -methyl naphthalene.....	$C_{10}H_7-\alpha-CH_3$	-20	240-243
$\beta$ -methyl naphthalene.....	$C_{10}H_7-\beta-CH_3$	32.5	241-242
1, 4-dimethyl naphthalene.....	$C_{10}H_6$ , -1-4-( $CH_3$ ) <sub>2</sub>	Liquid	262-264
$\alpha$ -ethyl naphthalene.....	$C_{10}H_7-\alpha-C_2H_5$	do.	258
$\beta$ -ethyl naphthalene.....	$C_{10}H_7-\beta-C_2H_5$	-19	351
Butyl naphthalene.....	$C_{10}H_7.C_4H_9$	—	280
$\alpha$ -phenyl naphthalene.....	$C_{10}H_7-\alpha-C_6H_5$	0	325
$\beta$ -phenyl naphthalene.....	$C_{10}H_7-\beta-C_6H_5$	102	347
—	$C_{27}H_{46}$	—	310-315 at 60 mm.
—	$C_{29}H_{50}$	—	340-345 at 60 mm.

(The last two members have specific gravities of 0.9451 and 0.9778, respectively, at 20° C.: the index of refraction of the former is 1.5146.)

(Mabery, Proc. Amer. Acad., 40, 340, (1904-1905): Richter, Organic Chem., 2, 3rd ed., 394).

## ANTHRACENE GROUP

TABLE 9: ANTHRACENE SERIES

(Engler-Höfer)

Name	Formula	Melting Point, °C.	Boiling Point, °C.
Anthracene.....	$C_{14}H_{10}$	213	351
Phenanthrene.....	$C_{14}H_{10}$	99	340
Pyrene.....	$C_{16}H_{10}$	—	—
Chyresene.....	$C_{18}H_{12}$	250	448
Retene.....	$C_{18}H_{18}$	98	394
Picene.....	$C_{22}H_{14}$	345	520
Carbopetrocene.....	$C_{24}H_8$	268	—
— *	$C_{24}H_{12}$	120	—
Benzerythrene.....	$C_{24}H_{18}$	307-308	—
Crackene.....	$C_{24}H_{18}$	308	—
Petrocene.....	$C_{26}H_{22}$	300	—
—	$C_{16}H_{10}$	250.5	—
—	$C_{16}H_{12}$	221.5	—
Thallene.....	$C_{14}H_{10}$	—	—

\* Specific gravity 1.096 at 15° C.

Hydrocarbons of the series  $C_nH_{2n-8}$ ,  $C_nH_{2n-10}$ , and  $C_nH_{2n-12}$ , have been found in high boiling fractions (208-250° C. at 760 mm.) from Caucasian oils.<sup>1</sup> Members from the anthracene series have been isolated from different petroleums. Some of these are shown in Table 9.

<sup>1</sup> Markownikoff, Liebig Annalen d. Chem., 234, 115 (1886).



## OXYGEN AND ITS COMPOUNDS

These are found in crude petroleum in various forms, viz.:

1. Free oxygen.
2. Fatty acids and their derivatives.
3. Naphthenic acids.
4. Phenols.
5. Asphaltic and resinous bodies.

The oxygen content of crude oil is generally about 2-3 per cent., although oils with a much higher oxygen content (3.6 to 6.9 per cent.) have been found.<sup>1</sup>

TABLE 20: NAPHTHENIC ACIDS IDENTIFIED IN CRUDE PETROLEUM

Name	Formula	Boiling Point, °C.	Specific Gravity
Hepta naphthenic acid . . . . .	$C_6H_{11}.COOH$	215-217	0.95025 at 18.4°
Octa naphthenic acid . . . . .	$C_7H_{13}.COOH$	237-239	0.9820 at 18°
Nona naphthenic acid . . . . .	$C_8H_{15}.COOH$	251-253	0.9795 at 20°
Deca naphthenic acid . . . . .	$C_9H_{17}.COOH$	—	—
Undecanaphthenic acid . . . . .	$C_{10}H_{19}.COOH$	258-261	0.982 at 0°
Dodecanaphthenic acid . . . . .	$C_{11}H_{21}.COOH$	—	—
Tridecanaphthenic acid . . . . .	$C_{12}H_{23}.COOH$	—	—
Tetradecanaphthenic acid . . . . .	$C_{14}H_{25}.COOH$	—	—
Pentadecanaphthenic acid . . . . .	$C_{14}H_{27}.COOH$	300-310	0.951 at 15°

(Engler-Hofer.)

The naphthenic acids are of the general formula

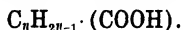


Table 20 gives a list of some members which have been separated from crude oil.

Oxygen compounds of the nature of phenols are found in petroleum from various fields. They occur in very small amounts in German oil,<sup>2</sup> and in Baku oil,<sup>3</sup> and in appreciable amounts in California oil<sup>4</sup> from the Ventura district. Richardson found 11, 12 and 14 per cent. of the distillates boiling between 15°-

<sup>1</sup> St. Claire-De Ville, Lit. Zitate u. weit. Sauerstoffgehalte S. Bei. Element zu samm. d. Roherdöle, 220.

<sup>2</sup> Kraemer-Böttcher, Ber. d. d. chem. Ges, 20, 595 (1887).

<sup>3</sup> Markownikoff-Ogloblin, Ber. d. d. chem. Ges., 16, 1873 (1883).

<sup>4</sup> Richardson, Jour. Franklin Instit., 161-162, 57, 81 (1906).

250° C. at 26 mm, to consist of phenoloid bodies which were removed by sodium hydroxide.

The asphaltic and resinous bodies which are present in most petroleum in various amounts are evidently formed in part by the oxidation and polymerization of certain hydrocarbons in the crude oil.

### SULPHUR AND ITS COMPOUNDS

Sulphur occurs to some extent in all petroleum, usually in one of the following forms: <sup>1</sup>

1. Free sulphur.
2. Hydrogen sulphide.
3. Organic sulphur compounds:
  - a. Thiophene,  $C_4H_4S$ , and its homologues.
  - b. Thiopane of the general formula  $C_nH_{2n}S$ .
  - c. Sulphones of the general formula  $C_nH_{2n}SO_2$ .
4. Alkyl sulphides of the general formula  $(C_nH_{2n+1})_2S$ .
5. Mercaptans or alkyl hydro sulphides  $(C_nH_{2n+1}SH)$ .
6. Alkyl sulphates of the general formula  $(C_nH_{2n+1})_2SO_4$ .

TABLE 21: SULPHUR COMPOUNDS SEPARATED FROM CANADIAN PETROLEUM

Formula	Boiling Point, °C., at 50 mm.	From Fractions, °C.	Sulphones Obtained
$C_7H_{14}S$ .....	71-73	87-89	$C_7H_{14}SO_2$
$C_8H_{16}S$ .....	79-81	97-99	$C_8H_{16}SO_2$
$C_9H_{18}S$ .....	97-98	110-115 at 50 mm.	$C_9H_{18}SO_2$
$C_{10}H_{20}S$ .....	110-112	129-131	$C_{11}H_{22}SO_2$
$C_{10}H_{20}S$ .....	114-116	142-144 at 50 mm.	$C_{12}H_{24}SO_2$
$C_{11}H_{22}S$ .....	129-131		
$C_{14}H_{28}S$ .....	168-170		
$C_{15}H_{30}S$ .....	198-200		

(Mabery-Quayle, Jour. Soc. Chem. Ind., 19, 505 (1900).)

The sulphur compounds of Table 21 were separated by Mabery <sup>2</sup> from Canadian petroleum. The method of separation consisted in extracting the sulphur compounds from the distillate in the refinery with sulphuric acid and precipitating by diluting with water. The precipitated oil contained a mixture of un-

<sup>1</sup> Waters, Tech. Paper 177, Bureau of Standards.

<sup>2</sup> Mabery-Quayle, J. Soc. Chem. Ind., 19, 505 (1900).

saturated hydrocarbons, sulphur compounds and other bodies. The sulphur oil was distilled in vacuum in porcelain stills and the fractions redistilled several times. Each fraction was then treated with an alcoholic mercuric chloride solution. The sulphur compound combined with the mercuric chloride and was precipitated out. After washing the mercuric chloride precipitate well with gasoline and alcohol, it was decomposed by hydrogen sulphide. The sulphur compound was dissolved in alcohol and was then precipitated by dilution. The sulphur oil was finally fractionally distilled in vacuum.

Alkyl sulphides were found in Ohio crude. Mabery<sup>1</sup> isolated from this crude ten members of the series, from methyl sulphide  $(CH_3)_2S$ , to hexyl sulphide,  $(C_6H_{13})_2S$ .

In general, crude oil of high specific gravity contains a higher percentage of sulphur than that of lower specific gravity, as shown by Table 22.

TABLE 22: RELATION BETWEEN GRAVITY AND SULPHUR CONTENT

Source	Specific Gravity	Baume Gravity	Per Cent Sulphur
West Virginia .....	.8073	43.4	0.067
Pennsylvania .....	.8139	42.0	0.07
Caddo, Louisiana .....	.8288	38.9	0.22
Indian Territory .....	.8365	37.6	0.26
Ohio .....	.836	37.5	0.72
Ohio .....	.8367	37.3	0.48
Illinois .....	.8547	33.8	0.20
Kansas .....	.8547	33.8	0.32
Petrolia, Canada .....	.862	32.4	1.00
Kansas .....	.865	31.8	0.37
Beaumont, Texas .....	.912	23.5	1.75
Ventura, California .....	.912	23.5	0.40
Mexican .....	.9174	22.6	2.33
McKittrick, Calif. ....	.9458	18.0	0.87
Mexican .....	.9750	13.6	3.12
Santa Barbara .....	.9845	12.2	0.84

#### NITROGEN AND ITS COMPOUNDS

Nearly all petroleum contains nitrogen bases (quinolines) in varying proportions. Some California oils contain as much

<sup>1</sup> Mabery-Smith, Amer. Chem. Jour., 13, 232 (1891).

as 10–20 per cent.<sup>1</sup> Japanese petroleum from some fields contains almost as much nitrogen as California oil.<sup>2</sup>

Mabery investigated the nitrogen compounds in California oils. The final main fractions obtained by distillation under 50–90 mm. pressure were, according to analyses and molecular weight determination, as given in Table 23. The conclusion is

TABLE 23: NITROGEN COMPOUNDS FOUND IN CALIFORNIA PETROLEUM

Formula	Fractions °C	Formula	Fractions °C.
C <sub>12</sub> H <sub>17</sub> N .. . . .	130–140°	C <sub>15</sub> H <sub>19</sub> N .. . . .	223–225°
C <sub>12</sub> H <sub>18</sub> N .. . . .	197–199	C <sub>16</sub> H <sub>19</sub> N .. . . .	243–245
C <sub>14</sub> H <sub>19</sub> N .. . . .	215–217	C <sub>17</sub> H <sub>21</sub> N .. . . .	270–275

(Mabery, J. Soc. Chem. Ind., 19, 505 (1900).)

that these bases consist chiefly of alkylated quinolines or iso quinolines (quinoline itself = C<sub>9</sub>H<sub>7</sub>N) and that three alkyl groups are united, to the  $\alpha$ ,  $\beta$  and  $\gamma$  carbon atoms of the nitrogen-containing ring in all from the lowest to the highest members.<sup>3</sup> These bases have a high specific gravity and an extremely pungent odor. They dissolve in acids, forming extremely weak salts. Table 24 shows the per cent. of nitrogen found in crude oils from different localities.

TABLE 24: NITROGEN FOUND IN DIFFERENT PETROLEUMS

Source	Per Cent. Nitrogen	Source	Per Cent. Nitrogen
West Virginia .. . . .	0.54	Japan .. . . .	0.35–1.34
Ohio .. . . .	0.02–0.35	China .. . . .	0.02
California .. . . .	0.5–1.46	Germany .. . . .	trace–1.1
Texas .. . . .	above 1.0	Italy .. . . .	0.04
Canada .. . . .	0.16–0.18	Egypt .. . . .	0.3–0.6
South America .. . . .	0.32	Algier .. . . .	2.17
Russia .. . . .	0.05–0.14		

(Engler-Höfer: Das Erdöl, 1, 479–80)

<sup>1</sup> Mabery, J. Soc. Chem. Ind., 19, 505 (1900).

<sup>2</sup> Mabery, J. Soc. Chem. Ind., 19, 504 (1900).

<sup>3</sup> Mabery-Wessen, J. Amer. Chem. Soc., 42, 1014 (1920).

## CHAPTER IV

### PHYSICAL PROPERTIES OF PETROLEUM AND ITS PRODUCTS

BY T. T. GRAY AND D. DROGIN

#### COLOR

The color of petroleum by transmitted light varies from light yellow to red, while some very dark grades are opaque. By reflected light, crude oil is usually green, on account of fluorescence. Pure hydrocarbons are colorless, but become colored upon oxidation, especially upon oxidation of the unsaturated members. The compounds yielding color belong to the aromatic class of hydrocarbons and the resulting color depends upon their molecular structure. Leuco bases, while colorless themselves, yield color bases upon the addition of a single atom of oxygen. This color base is also colorless, but has the power to unite with certain other elements or groups to give colored compounds. Again, color may be due to groups known as chromophores. This is the name given by Witt to certain unsaturated groups of atoms which have a powerful influence in producing color and are necessary for such production. The most important of these chromophores are:  $C=C$ ,  $C=O$ ,  $C=S$ ,  $C=N$ ,  $N-N$ ,  $N=O$ ,  $O=N=O$ . The chromophores unite in turn with other groups of elements, and form larger groups also essential to color, known as chromogens. These chromogens may be colored or not: if colorless they are capable of uniting with other groups known as auxochromes which give to the molecule both color and the power to form salts which are colored.  $NH_2$  and the  $OH$  groups are examples of auxochromes. In general, the depth of color in organic compounds is directly proportional to the molecular weight.

The color of petroleum varies in shade with the specific gravity of the oil, being yellow for light gravity oils (0.777-0.789), amber for medium (0.792-0.820) gravity oils and dark for oils of heavier specific gravity.

## FLUORESCENCE OR "BLOOM"

All oils exhibit the property of fluorescence in varying degrees. This property may be observed when the oil is seen by reflected light. Oil viewed in this manner appears to have a bluish tint. This is known as fluorescence. It is due to the stimulus given to the waves of light as they enter the oil. Certain wave-lengths are stimulated more than others. The blue wave-length receives the greatest stimulus; hence the bluish color of the oil.

## ODOR

The nature and composition of crude oil usually determines its odor. Unsaturated hydrocarbons, sulphur and certain nitrogen compounds are responsible for disagreeable odors. Crude petroleum from California, Russia and Roumania has an aromatic odor; Pennsylvania petroleum has an agreeable gasoline-like odor. Other oils vary in odor depending on the quantity of light hydrocarbons present in the oil, and of the impurities present. The petroleum from South Texas and Mexico has a strong disagreeable odor, due to hydrogen sulphide and other sulphur compounds.

## SPECIFIC GRAVITY

Petroleum is lighter than water. The specific gravity is influenced by physical factors and by the chemical composition of the crude oil. American crude petroleum varies in specific gravity from 0.7684 to 0.9960; Russian petroleum, from 0.854 to 0.899; Galician crudes from 0.799 to 0.902; and Mexican oil from 0.975 to 0.992. In practical operation in the petroleum industry the specific gravity is generally expressed in terms of the Baumé scale, which bears no direct relation to the specific gravity. The conversion of the Baumé scale into specific gravity, according to the modulus of the Bureau of Standards is as follows:

$$\text{Degrees Baumé} = \frac{140}{\text{Sp. Gr. } 60^{\circ}/60^{\circ} \text{ F.}} - 130$$

$$\text{Sp. Gr. } 60^{\circ}/60^{\circ} \text{ F.} = \frac{140}{130 + \text{deg. Bé.}}$$

## INDEX OF REFRACTION

The term "Index of Refraction" has reference to the change in the velocity of a ray of light traversing media of different densities. When one looks at an object resting on the bottom of a vessel containing water, the object appears to be nearer the surface of the vessel than it would if the vessel were empty; or, in other words, the object appears to be displaced from its true position. The only way in which the phenomenon can be explained is that the ray of light must diverge from its original path. This divergence of light rays from their path in one medium, upon passing into another, is known as refraction. It is caused by the change which the velocity of light undergoes in passing from one medium into another medium of different density. If a ray of light traversing the air were to strike upon a piece of glass, the ray in passing through the glass would be bent out of its original direction: for the velocity of light in glass is smaller than its velocity in air; and in order to traverse a certain distance in a given time it must choose a shorter path. If the light passing through the air were to fall perpendicularly upon a sheet of glass, its direction would undergo no change, because it would then be moving in the shortest possible path. The divergence takes place only when the light is traveling at an angle with a line perpendicular to the surface against which it strikes, called the normal. When a ray of light passes from one medium into a denser one, the ray is bent toward the normal; when it passes from a dense medium into a lighter one, it is bent away from the normal. The angles which the ray of light makes with the normal in passing from one medium into the other, must bear a definite relation to each other, since the velocity of the light undergoes a definite diminution. This relationship is expressed by the index of refraction, which is the ratio of the sine of the angle which the path of the ray makes with the normal in one medium, to the sine of the angle which it makes with the normal in the other medium. This when worked out numerically is found to be a constant for the same two media regardless of the size of the angles.

TABLE 10: INDICES OF REFRACTION

	Specific Gravity	Refractive Index
Pennsylvania crude oil .....	0.7531	1.4247
“ “ “ .....	0.7549	1.4263
“ “ “ .....	0.7580	1.4275
“ “ “ .....	0.7624	1.4330
Russian crude oil .....	0.7780	1.4377
“ “ “ .....	0.7855	1.4405
“ “ “ .....	0.8047	1.4471
“ “ “ .....	0.8165	1.4559

(Engler-Höfer.)

The index of refraction varies with the specific gravity of the oil. The heavier the oil, the higher is the refraction index. This is shown in Table 10. Values of the indices for petroleum distillates are given in Table 11. As the boiling points and specific gravities of the fractions increase, the indices increase likewise.

TABLE 11: INDICES OF REFRACTION FOR DIFFERENT FRACTIONS

Source	140°-160° C.		190°-210° C.		240°-260° C.		290°-310° C.	
	Sp. Gr.	n	Sp. Gr.	n	Sp. Gr.	n	Sp. Gr.	n
Tegernsee .....	0.7465	1.427	0.7840	1.437	0.8130	1.451	0.8370	1.465
Pechelbronn (Elsass) ..	0.7750	1.421	0.7900	1.440	0.8155	1.454	0.8320	1.462
Ölheim (Hannover) ..	0.7830	1.435	0.8155	1.450	0.8420	1.468	0.8620	1.480
Pennsylvania .....	0.7550	1.422	0.7860	1.439	0.8120	1.454	0.8325	1.463
Baku .....	0.7820	1.436	0.8195	1.454	0.8445	1.467	0.8640	1.475

Sp. Gr. = specific gravity

n = index of refraction

(Engler: Verh. d. Ver. z. Bef. d. Gewerbe, 662, (1887).).

From Table 11 it is apparent that the refractive indices of the oils of Tegernsee and Pechelbron approach those of Pennsylvania oil, while the results from the Ölheim crude are nearly like those from Baku oil.



TABLE 12: INDICES OF REFRACTION AND SPECIFIC GRAVITIES OF NAPHTHAS AND KEROSENES

Crude Oil	Naphtha Boiling Point up to 150° C.		Crude Oil	Kerosene Boiling Point 150°-300° C.	
	Specific Gravity at 15° C.	Index of Refraction at 20° C.		Specific Gravity at 15° C.	Index of Refraction at 20° C.
Pennsylvania.....	0.706	1.392	Pennsylvania ..	0.789	1.437
" .....	0.716	1.398	" ..	0.790	1.438
" .....	0.722	1.400	" ..	0.792	1.439
Oklahoma.....	0.726	1.402	" ..	0.795	1.440
Pennsylvania.....	0.731	1.405	Oklahoma ..	0.808	1.445
California.....	0.733	1.406	" ..	0.811	1.448
Healdton.....	0.734	1.406	" ..	0.814	1.449
Oklahoma.....	0.736	1.407	" ..	0.815	1.451
" .....	0.741	1.410	California ..	0.820	1.452
S. Maria .....	0.744	1.410	Healdton ..	0.824	1.454
California.....	0.750	1.412	Russia .....	0.836	1.458
Russia.....	0.765	1.418	" ..	0.841	1.459
			California ..	0.842	1.463
			St. Maria ..	0.849	1.466
			Mexico .....	0.861	1.475
			California ..	0.878	1.476

(Rittman &amp; Egloff: J. Ind. Eng. Chem. 7, 582 (1915).)

Cr. Predescu<sup>1</sup> found the index of refraction of a dark non-paraffin Roumanian crude (specific gravity at 15° C. = 0.8671) to be 1.487 at 15° C. The oil was distilled and 10° fractions between 50°-310° C. were examined. The index of refraction increased from 1.384 to 1.526. Table 12 shows the indices of refraction together with the specific gravities of naphtha and kerosene fractions from various crude oils.

#### OPTICAL ACTIVITY

Another phenomenon shown by petroleum is optical activity, or the power to rotate the so-called plane of polarized light. Ordinary light is recognized to be a wave motion in the universal ether. The light waves vibrate in all directions from the center of the disturbance. When a ray of ordinary light is incident upon a prism of Iceland Spar cut in a certain way (Nicol prism), the ray that emerges has somewhat different properties from those of the ray that enters the prism. If a second prism is

<sup>1</sup> Bull. sec. sci. acad. Roumaine, 6, 150-6 (1919-1920).

placed so that the emergent ray falls upon it, its axis may be turned so that the ray is cut off entirely. The ray after emerging from the first prism is vibrating in one plane only, instead of in all conceivable planes. Light vibrating in one plane only is known as polarized light. A ray of polarized light is strongly influenced by many organic compounds. If a compound containing an asymmetric carbon atom, i.e., an atom having its valence satisfied by four different groups or atoms, is placed in the path of a ray of polarized light, it acts in the same manner as a second prism would, cutting off the light. If the compound is placed between two appropriately crossed prisms, the light emerges again, showing that the plane in which the light vibrates is rotated by the compound so that the plane of rotation coincides with the direction of the axis of the second prism. This phenomenon is known as optical activity. Some compounds rotate light to the right, and are known as dextrorotatory; other compounds rotate the plane to the left, and are known as levorotatory compounds.

Engler claims<sup>1</sup> that nearly all petroleum are optically active. According to Jones,<sup>2</sup> American and Russian oils are usually dextrorotatory. The specific rotatory power is in either case very small. Predescu<sup>3</sup> examined two samples of dark nonparaffin crudes from Campina, Roumania; one sample (sp. gr. at 15° C. = 0.8671) was fractionated into ten fractions at atmospheric pressure. The fractions between 50°–220° C. showed no optical activity (500 mm. tube, Sodium light, new Pelvin polarimeter). The higher fractions showed very slight rotation under the same conditions. The other sample (sp. gr. at 15° C. = 0.8750) gave like results. Two light-colored crude oils (Govora and Parjol-Campen), as well as white naphtha from the Caucasus, Szurachany, Velleja and Montechino, were found to be optically inactive. According to Engler,<sup>4</sup> the optical activity in almost all petroleum is caused by the presence of a certain substance, prob-

<sup>1</sup> Zeit. fur. angew. Chem., 21, 1585–1597 (1908).

<sup>2</sup> Jones & Wooton, Jour. Chem. Soc. Trans., 2, 1149 (1907).

<sup>3</sup> Bull. sec. sci. Acad. Roumaine, 6, 181–8 (1919–1920).

<sup>4</sup> Op. cit., 21, 1585–1597 (1908).

ably the product of the destructive distillation of cholesterin or a cholesterol-like substance. (See Table 13.)

TABLE 13: OPTICAL ACTIVITY  
(Engler, Zeit. für angew. chem., 21, 1592 (1908).)

Source	Fraction °C.	Sacch. <sup>o</sup> 200 mm.	Pressure, mm.
Wietze (Hannover) . . . . .	235-275	+10.4	12
Baku (Bibi Eybath) . . . . .	230-278	+17.0	12-13
Galicia (Schodnica) . . . . .	260-285	+22.8(25)	12
Roumania (Campina) . . . . .	250-270	+22.0	12
Pechelbronn (Els.) . . . . .	265-281	+ 7.6	12.5
Pennsylvania . . . . .	255-297	+ 1.0	14
Java, Koeti IV . . . . .	282-286	+14.3	17.5
" Gogor . . . . .	285-296	+14.5	14.5
" Roengkoet . . . . .	268-281	+ 4.1	15.5

Cholesterin is found in both animal and vegetable matter, and is a constituent of new milk from fresh cattle. It is also found in blood, gall, and the nerves. It is an alcohol with the formula  $C_{26}H_{45}OH$ . Cholesterol is simply another name for cholesterin.

#### COEFFICIENT OF EXPANSION

TABLE 14: RELATION OF COEFFICIENT OF EXPANSION  
TO SPECIFIC GRAVITY, FOR BAKU OILS

Specific Gravity	Coeff. of Expansion per 1° C.	Specific Gravity	Coeff. of Expansion per 1° C.
0.700-0.720	0.000820	0.860-0.865	0.000700
0.720-0.740	0.000810	0.865-0.870	0.000692
0.740-0.760	0.000800	0.870-0.875	0.000685
0.760-0.780	0.000790	0.875-0.880	0.000677
0.780-0.800	0.000780	0.880-0.885	0.000670
0.800-0.810	0.000770	0.885-0.890	0.000660
0.810-0.820	0.000760	0.890-0.895	0.000650
0.820-0.830	0.000750	0.895-0.900	0.000640
0.830-0.840	0.000740	0.900-0.905	0.000630
0.840-0.850	0.000720	0.905-0.910	0.000620
0.850-0.860	0.000710	0.910-0.920	0.000600

(Rakuskin, Untersuch. d. Erdöls, 29 (1906).)

The coefficient of expansion of petroleum oils increases as the specific gravity decreases (see Table 14) for Baku oil. According to information contained in Circular No. 57 of the United States Bureau of Standards, the rate of this increase is not uniform.<sup>1</sup> (Table 15). The rate of change in specific grav-

<sup>1</sup> Anderson, J. Ind. Eng. Chem., 12, 1011 (1920).

TABLE 15: COEFFICIENT OF EXPANSION AT  
DIFFERENT TEMPERATURES

Specific Gravity at 60° F.	Change in Sp. Gr. for 1° F.	Specific Gravity at 60° F.	Change in Sp. Gr. for 1° F.
0.63 . . . . .	0.00053	0.79 . . . . .	0.00040
0.64 . . . . .	52	0.80 . . . . .	39
0.65 . . . . .	52	0.81 . . . . .	39
0.66 . . . . .	51	0.82 . . . . .	39
0.67 . . . . .	50	0.83 . . . . .	38
0.68 . . . . .	50	0.84 . . . . .	37
0.69 . . . . .	49	0.85 . . . . .	37
0.70 . . . . .	49	0.86 . . . . .	37
0.71 . . . . .	48	0.87 . . . . .	37
0.72 . . . . .	47	0.88 . . . . .	36
0.73 . . . . .	46	0.89 . . . . .	36
0.74 . . . . .	45	0.90 . . . . .	36
0.75 . . . . .	44	0.91 . . . . .	36
0.76 . . . . .	43	0.92 . . . . .	36
0.77 . . . . .	42	0.93 . . . . .	36
0.78 . . . . .	41		

(Anderson, J. Ind. Eng. Chem., 12, 1011 (1920).)

ity for a change in temperature of 1° F. amounts to  $0.23 \times 10^5$  for each 0.01 variation in specific gravity between 0.93 and 0.80, to  $1 \times 10^5$  between 0.80 and 0.70, and to  $0.57 \times 10^5$  between 0.70 and 0.63.

The coefficients of expansion of various crude oils are shown in Table 16. The coefficient varies with the temperature. See

TABLE 16: COEFFICIENT OF EXPANSION AND SPECIFIC  
GRAVITY OF CRUDE OILS

Source	Specific Gravity	Coefficient of Expansion
Pennsylvania . . . . .	0.816	0.000840
Canada . . . . .	0.828	843
Schwabweiler (Elsass) . . . . .	0.829	843
West Virginia . . . . .	0.841	839
Schwabweiler (Elsass) . . . . .	0.861	858
Wallachia . . . . .	0.862	808
Eastern Galicia . . . . .	0.870	813
Rangoon . . . . .	0.875	774
Caucasus . . . . .	0.882	817
Western Galicia . . . . .	0.885	775
Ohio . . . . .	0.887	748
Baku . . . . .	0.890	784
Oedesse (Hanover) . . . . .	0.892	772
Pechelbronn . . . . .	0.892	792
Wallachia . . . . .	0.901	748
Oberg (Hanover) . . . . .	0.944	762
Weitze (Hanover) . . . . .	0.955	647

(Engler, Verh. Ver. Beförd. Gewerbf. Preuss., 66, 643 (1887).)

Table 17 for results on Galician crude. Extensive experiments

TABLE 17. COEFFICIENT OF EXPANSION AT DIFFERENT TEMPERATURES OF GALICIAN PETROLEUM

Temperature in °C.	Coefficient of Expansion
1 .....	0.001095
10 .....	0.001103
20 .....	0.0009643
30 .....	0.0008587
40 .....	0.0008505

have been carried out by Holde,<sup>1</sup> the conclusions of which are as follows: the less viscous oils, whose specific gravity is lower than 0.905, show between 20° and 78° C. a coefficient ranging from 0.00072 to 0.00076. Those containing paraffin, and solid below 20° C., give a coefficient ranging from 0.00075 to 0.00081. Heavy viscous mineral lubricating oils with a minimum specific gravity of 0.908 show little variation in the coefficient of expansion, which is between 0.00070 and 0.00072.

#### VISCOSITY

The viscosity, or the measure of the tendency to flow, is an important factor with lubricating oils. It is usually determined as the time necessary for a definite volume of oil at a definite temperature to flow through a small opening or orifice. The actual work is carried out in an instrument known as a viscosimeter of which there are several standard makes in use at the present time. All of them employ the same general principle. The oil is heated in a metallic cup, surrounded by an oil bath. The temperature of the oil within the cup, and that of the oil bath, are carefully controlled; and when the desired temperature has been reached a small orifice in the bottom of the cup is opened and the oil is allowed to flow into a clean flask of known capacity. The time necessary for the flask to fill is taken as the measure of the viscosity of the oil.

Crude petroleums are quite variable in viscous character. Some are very mobile, while others, like Mexican crude, are quite viscid. Oils composed of hydrocarbons belonging to the

<sup>1</sup> Mittell. d. techn. Versuchs-Anst. Berlin, 11, 45-68 (1893).

series  $C_nH_{2n-2}$  and  $C_nH_{2n-4}$  are viscous. Heavy petroleum in general is composed to a large extent of these hydrocarbons.<sup>1</sup> The viscosity increases with the density. (See Table 18 and Table 19.) The viscosities of oils of the same specific gravity, but from different sources, are not always the same. This is due to the difference in chemical composition.

TABLE 18: VISCOSITIES AND SPECIFIC GRAVITIES OF  
PETROLEUM

Source	Spec. Gr. at 15° C.	Viscosities Engler Degrees		
		20° C.	50° C.	100° C.
Galicia . . . . .	0.855	1.65	1.23	1.02
Germany (Pechelbronn) . . . . .	0.891	5.24	2.04	1.26
Russia . . . . .	0.929	77.2	11.07	2.30
South America (Argentina) . . . . .	0.939	—	80.10	6.31
Roumania . . . . .	0.940	18.15	3.56	1.38
Mexico . . . . .	0.940	317.0	28.3	4.47
Germany (Hanover) . . . . .	0.941	136.4	17.70	2.43
South America (San Rafael) . . . . .	0.993	—	205.0	13.3

(Constan & Schl pfer, Zeit. d. Ver. deut. Ingen., Sept. 20, Oct. 4, 11, 18, 25, 1913.)

Predescu<sup>2</sup> has examined the viscosity and capillary constants of Roumanian (Campina) crude oil (sp. gr. = 0.875 at 15° C.).

The "capillary constant" measures the force necessary to keep a film of liquid from contracting. It is determined in the following way: A rectangular frame of wire is immersed in the liquid, the capillary constant of which is to be determined, and then partially withdrawn. If it were wholly withdrawn, the delicate film suspended upon the frame would tend to contract indefinitely until it burst. A force must therefore be applied to it to preserve the film. This is done by allowing part of the film to remain in the liquid. The liquid, because of the contracting force of the film, tends to draw the frame toward it; and just enough force is brought to bear upon the frame to prevent it from being drawn down into the liquid. It has been determined experimentally that this force is proportional to the width of

<sup>1</sup> Mahery, Mining & Metallurgy No. 153, Sec. 34, Feb., 1920.

<sup>2</sup> Bull. sec. sci. acad. Roumaine, 6, 188-196 (1919-1920).

the film. The factor which shows the numerical ratio of the force to the width of the film is called the capillary constant. It is given by the following equation:  $F/2L = T$ , in which  $F$  is the force exerted,  $2L$  is the width of the film on both sides of the frame, and  $T$  is the capillary constant.

TABLE 19: VISCOSITIES AND SPECIFIC GRAVITIES  
OF PETROLEUM

Source	Sp. Gr. at 15° C.	Viscosities, Engler Degrees at 20° C.		Surface Tension	Capillary Constant
		Spec.	Sec.		
Pennsylvania . . . . .	0.799	1.30	67.5	24.07	6.17
" . . . . .	0.800	1.29	67	25.12	6.44
" . . . . .	0.808	1.32	68.5	24.81	6.30
" . . . . .	0.816	1.40	73	25.44	6.38
Oklahoma . . . . .	0.825	1.44	75	24.78	6.15
" . . . . .	0.838	1.71	89	26.19	6.40
" . . . . .	0.846	1.70	88.5	25.03	6.06
Healdton . . . . .	0.865	2.77	144	26.59	6.30
Oklahoma . . . . .	0.870	3.35	174	26.59	6.26
California . . . . .	0.876	2.31	120	25.70	6.00
Russia . . . . .	0.876	2.61	136	27.55	6.43
" . . . . .	0.878	3.22	167.5	27.82	6.49
California . . . . .	0.891	2.11	110	26.08	5.99
S. Maria . . . . .	0.901	4.92	256	26.13	5.94

*Note:* The surface tension measurements were made by the use of the Morgan drop weight method. Values for the capillary constant were obtained from the formula.

$$a^2 = \frac{2\gamma}{9.8d}$$

$a^2$  = capillary constant

$\gamma$  = surface tension

$d$  = specific gravity

(Rittman & Egloff, J. Ind. Eng. Chem., 7, 578 (1915).)

The capillary constant of the Roumanian crude just mentioned was 2.77 (Laplace Formula) and that of its fractions up to 270° C. gradually increased from 2.20 to 2.89 (at 15° C.). The viscosities of these fractions, in Engler degrees, increased from 0.910 to 3.131.

The capillary constants show greater variations for these fractions than do the densities or the indices of refraction. The viscosities of the fractions increase much more rapidly than the

capillarities. This explains why fractions with high boiling points rise more slowly in a capillary than the fractions with low boiling points.

#### POUR AND COLD TESTS

The pour and cold tests are essential in determining the influence of a low temperature upon certain oils and are also indications of the amount of solid paraffins present. About 35 c.c. of the oil contained in a small glass bottle are immersed in a freezing bath or freezing mixture. A thermometer passes through a cork in the top of the glass bottle, with the bulb immersed in the oil. The bottle is surrounded with a freezing mixture, but protected from direct contact by a jacket. From time to time the bottle is removed and tilted. The temperature at which the oil just ceases to flow is observed and recorded as the cold test. The temperature obtained by the pour test is from two to five degrees higher, and is the temperature at which the oil was last fluid on the even five-degree divisions of the thermometer. The cloud test is the temperature at which the first cloud appears in the oil. The tentative method suggested by Committee D-2 of the American Society of Testing Materials recommends that the cloud test reading be taken when the oil in the bottom of the test bottle has become opaque to a thickness of from  $\frac{1}{8}$  to  $\frac{3}{16}$  of an inch. It would seem that the good points of the old-time cloud test would be lost by this change. This test was designed to show the presence of a solid amorphous paraffin or the contamination of pressed oils by traces of high melting point waxes; and indicated either that the original wax distillate was not properly distilled, or that it had become contaminated in some way so that solid amorphous hydrocarbons were present. These, on filter pressing, on account of their salve-like nature, passed right through the bags into the distillate, or else the canvas on the filter plates was in bad condition, allowing small quantities of wax to leak through. It would seem that this test is of value only when the first cloud is taken.

Lubricating oils become turbid or cloudy at relatively low tem-



peratures, although they may be perfectly clear at ordinary temperatures. This is due to the settling out of the solid paraffins. However, there are certain oils which may be perfectly clear at a temperature of 20° to 30° C. A wide range, say 15° F., between the cold test and the cloud test on oils made from pressed distillates indicates something to be wrong either at the crude stills or in the press house.

#### THE FLASHING AND BURNING POINTS

Another important examination made in connection with petroleum products is that of the flash and burning points. The flash point may be defined as the temperature at which the vapors arising from the heated oil will ignite with a flash of very short duration, when a small flame is passed over the surface. This is of the utmost importance, as it indicates the temperature at which the oil will ignite. When the oil is heated to a higher temperature, a point is reached where if a flame is brought near the surface, the oil will ignite and burn with a steady flame at the surface. The lowest temperature at which the oil vapors will burn with a steady flame is known as the burning point. In the oil industry, the flash and burning points are taken both in the open cup and in specially designed apparatus. When the open cup is employed, the oil is heated in a metal cup with a thermometer suspended so that the bulb is below the surface of the oil. The temperature is raised a certain number of degrees per minute, generally ten, and a small gas flame is occasionally passed from left to right over the surface of the oil. When a momentary flash is seen, the temperature is recorded as the flash point. The temperature is then raised at the same rate, and when a permanent flame is seen the temperature is recorded as the burning point. These tests must be conducted in a room free from drafts, preferably darkened. The flash and burning points of kerosene are fixed by law in each state.

#### SPECIFIC HEAT

The specific heat of the hydrocarbons in each series decreases with increase in molecular weight. Normal hydrocarbons have higher specific heats than their isomers. The unsat-

urated hydrocarbons of the series  $C_nH_{2n}$  (ethylene series) have lower specific heats than the corresponding members of the paraffin series,  $C_nH_{2n+2}$ .

Pawlewski<sup>1</sup> determined the specific heat of different Galician crudes and some of their products and found:

1. Hydrocarbons of high molecular weight had a small heat capacity, scarcely 0.2 to 0.3 of the heat capacity of water.
2. Some fractions composed of light hydrocarbons had a much higher specific heat than the original crude.
3. Oils, vaselines and paraffins, composed chiefly of heavy hydrocarbons, had a lower specific heat than the light boiling fractions; some even lower than that obtained for the crude oil itself.
4. The specific heat of paraffins changed markedly with the temperature. At high temperatures, the values approached that of water.

Table 25 lists the specific heats of various crude oils. Table 26 gives the specific heats of different samples of crude oil from California, with a variable asphaltic content. Table 27 shows the specific heats of petroleum fractions from Russian, Baku and Roumanian crude.

TABLE 25: SPECIFIC HEATS OF CRUDE OILS

Source	Specific Gravity	Specific Heat
Berea Grit.....	0.7939	0.4690
Pennsylvania.....	0.8095	0.5000
Roumania (Policiori).....	0.8291 at 15°	0.4724 bet. 14-20°
Roumania Bustenari.....	0.8424 at 15°	0.4625 "
Roumania Campina.....	0.8694 at 15°	0.4667 "
Japanese.....	0.8622	0.4532
Roumania (Campina).....	0.8548 at 15°	0.4675 bet. 14-20°
Wyoming.....	0.8316	0.4323
Russian.....	0.9079	0.4355
Texas (Lucas well).....	0.9200	0.4315
Texas.....	0.9466	0.4009
California.....	0.9600	0.3980
".....	—	0.4500
Ohio.....	—	0.4951

(Scheller and Gheorghin, *Petroleum*, 8, 533-534 (1912-1913);  
 Mabery and Goldstein, *Amer. Chem. Jour.*, 28, 74, (1902)  
 Wales, *Journ. Ind. Eng. Chem.* 6, 728 (1914).)

<sup>1</sup> *Chem.-Zeit. Repert.*, 17, No. 2, 313 (1893).

TABLE 26: SPECIFIC HEAT OF CALIFORNIA CRUDE OIL

No.	Distillate Percentage					Specific Heat at 20° C.
	Water	0-150° C.	150-300° C.	300° Asphalt	Asphalt	
1	0	—	—	—	—	0.3999
2	0.33	—	—	—	—	0.4143
3	0.52	—	—	—	—	0.4389
4	7.0	5.7	23.14	32.1	31.7	0.5016
5	1.3	0	37.4	30.0	30.91	0.4788
6	0	35.6	54.1	4.2	6.2	0.4804
7	0	8.1	27.3	39.7	23.5	0.4474
8	0	25.8	43.3	22.1	7.0	0.4832
9	0	0	12.3	48.7	36.3	0.4419
10	0	0	22.5	42.3	34.7	0.4553
11	6.2	0	30.9	22.6	39.9	0.4559
12	0	0	34.1	30.2	35.4	0.4491

(Wales, Journ. Ind. Eng. Chem., 6, 727-728 (1914).)

Karawajeff<sup>1</sup> determined the specific heat of heavy fractions of petroleum oils by means of a Bunsen ice calorimeter. He found that the mean specific heat of the fractions examined increased rapidly with the temperature. The specific heat of most of the fractions approximated 0.48 at 100° C. but rose to about 0.60 at 400° C. Between 100° and 400° C., the specific heat could be expressed with sufficient accuracy, as a linear function of the temperature. The specific heat of petroleum fractions of different specific gravities differed but slightly at the same temperatures.

Wales,<sup>2</sup> on examination of different crudes from California, found that as the asphaltic content of the crude increased, the specific heat decreased.

#### HEAT OF VAPORIZATION

The heat of vaporization decreases with increase in molecular weight. Table 28 shows the heat of vaporization of some mineral oils.

Graefe<sup>3</sup> determines the heat of vaporization of mineral oils in the following way: The average molecular weight of the oil

<sup>1</sup> Karawajeff, *Petroleum*, 2, 550 (1913-1914).<sup>2</sup> Journ. Ind. Eng. Chem., Vol. 6, 727-728 (1914).<sup>3</sup> *Petroleum*, 5, 569-570 (1910).

TABLE 27: SPECIFIC HEATS OF FRACTIONS FROM DIFFERENT PETROLEUMS

Nature	Specific Gravity at 15° C.	Boiling Point, °C.	Flash Point, °C., Open Cup	Specific Heat
Russian:				
Solar oil .....	0.8863	—	138	0.5191
Mazout I. ....	0.9166	—	167	0.501
Mazout II. ....	0.9186	—	202	0.502
Machine oil .....	0.9098	—	208	0.4988
Cylinder oil .....	0.9185	—	245	0.495
Tar oil .....	0.9465	—	294	0.505
Paraffin oil .....	0.8687	—	25-26 congeal. point	0.5424
Roumania:				
Light benzine .....	0.7125	47-132	—	0.484
Heavy benzine .....	0.7464	84-154	—	0.4679
Lamp oil .....	0.8142	141-300	—	0.4652
Gas oil .....	0.8642	228-360	Viscosity Engler at 20°	0.4619
Light spindle oil. ...	0.9043	292-390	2.9	0.4597
Refined oil I. ....	0.9100	—	5.5	0.4579
Refined oil II .....	0.9319	—	16.1	0.4567
Naphthenic Acid. ....	0.9658	(technically pure)	—	0.4630
Baku:				
— .....	0.7535 at 20°	91.5	—	0.508
— .....	0.753 at 22°	109-112	—	0.520
1 .....	0.7524 temp. not given	100-165	—	0.459 bet. 15-20°
2 .....	0.8045 temp. not given	165-170	—	0.469 bet. 15-20°
3 .....	0.8089 temp. not given	170-175	—	0.457 bet. 15-20°
4 .....	0.8432 temp. not given	235-240	—	0.449 bet. 15-20°
Lubricating oil .....	0.869 at 19.5°	—	—	0.452
Lubricating oil .....	0.9095 at 20°	—	—	0.550
Russian:				
Kerosene .....	0.8248	—	—	0.435 bet. 12-15°
Fuel oil .....	0.914	—	—	0.448 bet. 12-15°
Burma:				
Fuel oil .....	0.897	—	—	0.433 bet. 12-15°
Texas:				
Fuel oil .....	0.927	—	—	0.436 bet. 12-15°
Roumanian:				
Kerosene .....	0.8127	—	—	0.444 bet. 12-15°

(Schmitz-Matiers; Grasse-No. 58, 3007 (Feb., 1913): Engler-Höfer; Scheller & Gheorghiu, Pet., 533, 534 (1912-1913).) Redwood, Petroleum, 1, 222 (1913).

is determined by the freezing point method, using stearic acid as a solvent. The average boiling point of the oil is then determined by a continuous Engler distillation, first noting the initial boiling point, then the boiling points when 10, 20, 30, 40, 50, 60, 70, 80, 90 and 98 (or thereabout) per cent. of the distillate has distilled over. The temperatures of the eleven observations are added and the sum is divided by eleven. The quotient is the average boiling point. The average absolute boiling point is obtained by adding 273 to the average boiling point.

The heat of vaporization is then obtained by using Trouton's rule (the molecular heat of vaporization divided by the absolute boiling point equals a constant, which is about 20), and adding this to the heat required to raise the oil from room temperature (25°) to the boiling point, on the basis of a specific heat of 0.42 to 0.43, which holds for all mineral oils. The calculation of the heat of vaporization of the light crude oil in Table 28 is as follows:

TABLE 28: HEAT OF VAPORIZATION OF MINERAL OILS

Nature	Specific Gravity	Average Molec. Wt.	Average Boiling Point	Average Boiling Point, Absolute	Heat of Vapor.	Heat to Raise to Boiling Point	Total Heat of Vapor. (Calc.)
Light crude oil.....	0.883	113	216° C.	489° C.	<i>cal.</i>	<i>cal.</i>	<i>cal.</i>
Heavy crude oil.....	0.905	158	270	543	86.5	82	168.5
Gas oil.....	0.890	158	273	546	68.7	105	173.7
Light paraffin oil.....	0.920	190	328	601	69.2	107	176.2
Heavy paraffin oil.....	0.933	230	346	619	63.3	130	193.3
Putz oil.....	0.854	148	219	492	53.8	138	191.8
					66.5	83	149.5

(Graefe, Petroleum, No. 5, 569-570 (1910).)

Average boiling point = 216°.

Average boiling point absolute = 216 + 273 = 489°.

Average molecular weight = 113.

Trouton's law is  $\frac{\text{Mol. heat of Vaporization}}{\text{Absolute Boiling Point}} = K = 20$

or

$$\begin{aligned}\text{Heat of Vaporization} &= \frac{20 \times \text{Absol. Boiling Pt.}}{\text{Molecular weight}} \\ &= \frac{20 \times 489}{113} = 86.5 \text{ cal.}\end{aligned}$$

The value 86.5 calories is the heat required for converting the boiling oil from the liquid state into the vapor state. The number of calories necessary to bring the oil from room temperature (25° C.) to the average boiling point of 216°, is calculated as follows:

The specific heat of the mineral oil is about 0.43.

$$(216^\circ - 25^\circ) \times 0.43 = 82 \text{ calories.}$$

The total heat of vaporization is therefore:

$$86.5 + 82 = 168.5 \text{ calories.}$$

#### CALORIFIC VALUE

The calorific values of different crudes are reported in Table 30. Sherman and Kropff<sup>1</sup> found a relation between the specific gravity and the calorific power. They examined different American crudes and some of their fractions, and from the experimental results arrived at the following formula:

$$\text{B.t.u.} = 18,650 + 40 (\text{Baumé degrees} - 10)$$

There is a decrease in calorific power as the specific gravity increases or as the Baumé degrees decrease.

A rough summary of the work of Sherman and Kropff is shown in Table 29, where the relation between specific gravities of similar oils and their calorific powers is shown.

TABLE 29: SPECIFIC GRAVITY AND CALORIFIC VALUE OF PETROLEUM AND ITS PRODUCTS

Specific Gravity	Calorific Power
0.7-0.75	11,700-11,850 cal.
0.75-0.80	11,350-11,100 cal.
0.80-0.85	11,100-10,875 cal.
0.85-0.90	10,875-10,678 cal.
0.90-0.95	10,675-10,500 cal.

.(Sherman & Kropff, J. Amer. Chem. Soc., 30, No. 2, 1630 (1908).)

<sup>1</sup>J. Amer. Chem. Soc., 30, No. 2, 1626 (1908).

TABLE 30: CALORIFIC VALUES OF DIFFERENT CRUDES

Source	Specific Gravity	Heating Value, Calories per Gram
California:		
Kern River . . . . .	0.9645 at 15°	13,307
Coalinga . . . . .	0.9498 "	10,404
McKittrick . . . . .	0.9566 "	10,282
Midway . . . . .	0.9570 "	10,341
Sunset . . . . .	0.9701 "	10,266
Texas . . . . .	0.9200	10,874
West Virginia:		
(heavy) . . . . .	0.873 at 0°	10,180
(light) . . . . .	0.8412 "	10,223
Pennsylvania:		
(heavy) . . . . .	0.886 "	10,672
(light) . . . . .	0.816 "	9,963
Mexico . . . . .	0.940 "	10,298
" . . . . .	0.929 "	10,373
Germany:		
Pechelbronn . . . . .	0.891 at 15°	10,648
" . . . . .	0.892 at 0°	10,020
" . . . . .	0.912 "	9,708
Hanover . . . . .	0.941 at 15°	10,577
Schwabweiler . . . . .	0.861 at 0°	10,458
East Galicia . . . . .	0.870 "	10,005
West Galicia . . . . .	0.885 "	10,231
Galicia . . . . .	0.855 at 15°	10,851
South America:		
San Rafael . . . . .	0.993 at 15°	10,299
Argentina . . . . .	0.939 "	10,686
Russia . . . . .	0.876 "	10,857
" . . . . .	0.902 "	10,758
Roumania . . . . .	0.940 "	10,511
Java . . . . .	0.923 at 0°	10,831
Balakhani . . . . .	0.822 at 0°	11,700
Baku (light) . . . . .	0.884 "	11,460
" (heavy) . . . . .	0.938 "	10,800

(Allen & Jacobs, Bur. Mines. Bull. No. 19: St. Claire Deville, Comp. Rend., 66, 442-453 (1868), 72, 192-198 (1871): Constan & Schläpfer, Zeit. des. Ver. deut. Ing., Sept. 20, Oct. 4, 11, 18, 25 (1913).)

#### BOILING POINT

Crude oils differ markedly in their boiling points and in the amount of distillate which is obtainable at definite temperatures (See Table 31). The boiling point of the crude will depend largely on the hydrocarbons which compose it. The more volatile the hydrocarbons, the lower is the boiling point. A petroleum of light specific gravity will usually contain a larger proportion of the more volatile hydrocarbons, whereas in a crude

of a high specific gravity, high boiling-point hydrocarbons generally predominate.

TABLE 31: BOILING POINTS OF DIFFERENT CRUDES AND AMOUNT OF DISTILLATES AT DIFFERENT TEMPERATURES

Source	Sp. Grav. C. 17° C.	Initial B. Pt. °C.	Per Cent by Volume Distilling at °C.										
			Below 130°	130-150	150-170	170-190	190-210	210-230	230-250	250-270	270-290	290-300	Above 300
Pennsylvania . . .	0.8175	82	15.0	6.0	5.0	5.0	5.0	5.75	4.75	6.0	4.74	2.0	40.75
Pennsylvania . . .	0.8010	74	24.5	7.0	4.5	4.5	6.5	5.0	4.75	3.25	4.0	2.5	33.5
Galicia . . . . .	0.8235	90	16.0	10.5	10.25	6.5	6.5	7.0	6.75	6.0	3.5	0.5	26.5
Baku (Bibi Eibat) . . .	0.8590	91	16.0	7.0	6.5	6.5	5.0	5.0	5.0	5.5	3.5	1.0	39.0
Baku (Baklakhani) . . .	0.8710	105	3.75	4.75	5.5	4.75	5.25	5.0	7.0	4.75	5.5	1.75	52.0
Pechelbronn . . .	0.9075	135	—	3.0	4.4	5.4	4.5	6.6	7.3	7.0	10.3	4.5	47.0
Hanover . . . . .	0.8990	170	—	—	—	4.75	5.25	6.0	4.0	5.0	5.0	2.0	68.0

(Engler & Levin, Dingler's Polytech. Jour., 261, 32 (1886).)



## CHAPTER V

### THE MANUFACTURING PROCESS

#### AN OUTLINE OF THE VARIOUS STEPS OF REFINING CRUDE OIL

There are so many different crudes, and the methods of handling them are so varied, that this chapter will not attempt more than to outline the usual practice. Differences in process work are largely in the details. The principles generally followed are about as here given.

The process of treating crude petroleum is always one of fractional distillation, with subsequent chemical treatment, filtering, re-distillation and compounding of each of the fractions. Sometimes one alone of the subsequent treatments produces the desired result; often two or more subsequent steps are taken.

There are three major classifications of petroleum:

Paraffin base,  
Asphalt base,  
Mixed base.

The first mentioned is an oil which contains very little asphalt but yields solid hydrocarbons of the so-called paraffin series, expressed by the general chemical formula  $C_nH_{2n+2}$ . These solid compounds form what is popularly known as paraffin wax. Some of the well-known paraffin base oils are those from the Pennsylvania, West Virginia, North Louisiana, Ranger, and certain of the Mid-Continent (Oklahoma and Kansas) fields. Generally speaking, the paraffin base oils are the most valuable. This is due, not alone to the valuable lubricating oils and cylinder stocks contained therein, but also to the fact that such oils usually show a high yield of gasoline.

The asphalt base crudes leave as a residue, a heavy pitch or asphalt. Predominating in this residuum are hydrocarbons of the naphthene series, expressed chemically by the general form-

ula  $C_nH_{2n}$ . California, certain Texas, and the heavy Mexican oils are of this class.

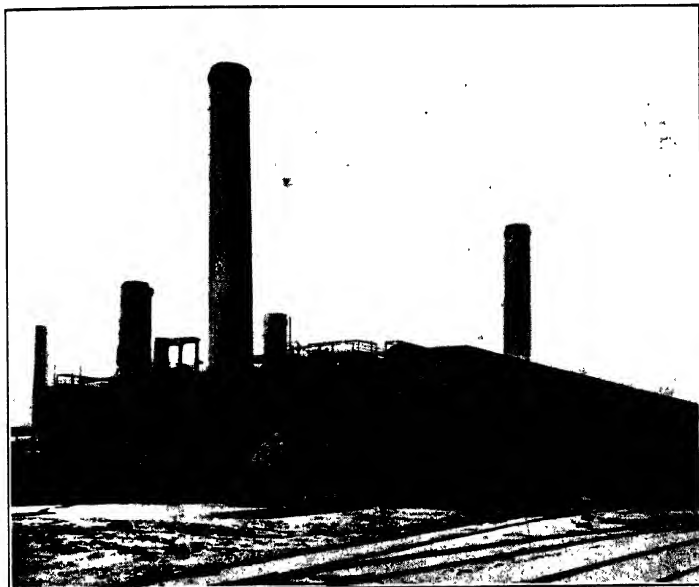


FIG. 1

Battery of crude stills at the East Chicago Refinery of the Sinclair Refining Company.

A mixed base petroleum is one in which both of the above compounds are found. Illinois, some of the Mid-Continent and light Mexican oils are of this class.

The three classes of crudes are handled somewhat similarly, but the yields of products are quite different. Paraffin base oils are usually run with every effort to avoid cracking or decomposition by heat. They yield the bulk of our high grade lubricants. Asphalt base crudes, on the other hand, will yield greater amounts of light products when cracked. Mixed base oils are usually refined by a combination of the two processes, cracking and non-cracking. \*

The two methods are usually termed "running to cylinder stock," and "running to coke." A brief outline of each follows:

**RUNNING TO CYLINDER STOCK:**

The crude oil is first distilled by direct firing with the aid of open steam sprays in the still. The stills in common use range from 200 to 1,200 barrels' capacity. These stills may be arranged to run continuously, pumping the oil into the first and the residuum from the last, or the oil may be run down completely in one still. The arrangement of stills and technology of distillation will be discussed in Chapter VII. As the oil is

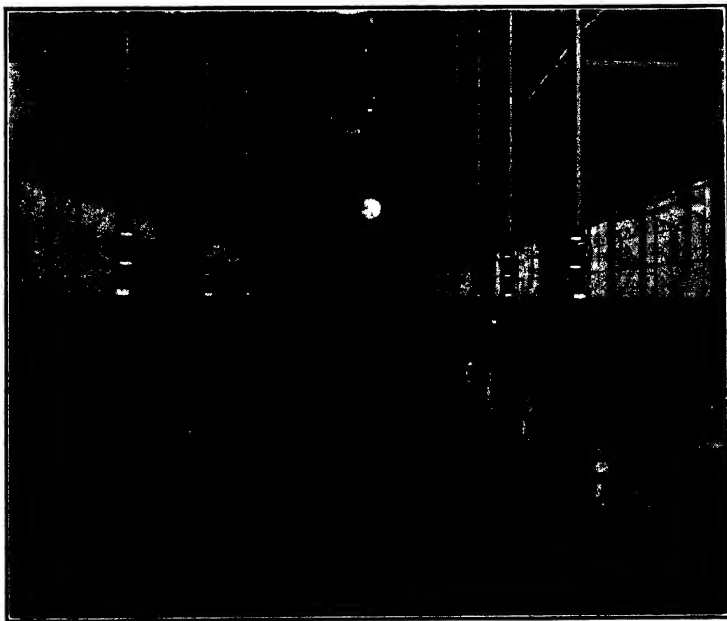


FIG. 2

Interior of receiving house.

heated, those portions of low boiling points vaporize, and are led through condensing coils to a so-called "look box." Here the stream is under the observation of the still man, who by means of samples keeps in touch with the operation. As the tempera-

ture of the oil in the still rises, fractions of higher boiling point and lower Baumé gravity are vaporized and condensed, and flow through the look box. The look box is connected to a manifold leading to the receiving tanks, one or more tanks being provided for each "cut" or product desired from the distillation.

The cuts or separations are usually differentiated by the gravity of the stream at the look box. Those resulting from the first distillation of crude Pennsylvania oil will run about as follows:

Crude naphtha .....	Start to 54° Baumé
Kerosene distillate .....	54° to 50° Baumé
Crude Kerosene .....	50° to 38° Baumé
Gas or fuel oil .....	38° to 35° Baumé
Wax distillate .....	35° to off Baumé

Various other cuts may be made; such, for instance, as mineral seal or mineral colza, which may be taken from the last of the kerosene distillate; for example, from 41° to 38° B. Or, the entire kerosene cut from 54° to 38° Baumé may be collected together. The above table represents average practice on this kind of crude oil. It should be noted that the use of open steam coils or so-called "bottom" steam has resulted in a residual stock suitable for the production of cylinder oils of a high grade. There are probably two reasons for this, each being the result of a low still temperature. Cracking, or decomposition, of the hydrocarbon molecules begins at temperatures around 300° C. (572° F.) The action of the steam spray on the bottom of the still prevents local overheating: the agitation keeps stirring up the oil. Without such agitation, the portions adjacent to the still bottom might be overheated. Convection currents, so easily set up with water, are much slower with petroleum. The most important result of the use of steam, however, is to lower the boiling point and thus to assist in removing the vapors from the still to the condenser at a reduced temperature. This reduction of the normal boiling point is due to a division of pressure between the oil vapors and the steam, the partial pressures of the vapors being lower than the pressure of the atmosphere.

The temperatures of distillation resulting from this practice run from 75° to 125° F. lower than the temperatures that would be necessary for the same cuts without the use of steam. The amount of steam used varies with different refiners and for different products, as will be later discussed.

Another method of reducing the boiling point is by the use of a vacuum while distilling. Vacuum stills must of course be strongly braced to withstand external pressure. To avoid this expense for all stills, some refiners run the crude down to about 35° Baumé in ordinary batch stills or continuous stills, and then transfer it to vacuum stills intended to take off the wax distillate cut. The wet vacuum system is the one almost always employed in this country, and it is a question whether the results obtained justify the increased expense. Owing to mechanical difficulties, it is difficult to maintain an appreciable vacuum in the still. The European dry vacuum system seems to offer greater possibilities.

The crude naphtha, or first cut, is collected and is the base of commercial naphthas and gasoline. The distillate will contain hydrocarbons of higher boiling point than are allowable in gasoline. Further distillation is therefore required. Prior to further distillation, the crude naphtha is subjected to treatment to remove any unsaturated hydrocarbons which might impart an unpleasant odor and color. This is done in either an agitator or a continuous treater; preferably the latter, because of the lower naphtha loss and reduced fire risk. (See Chapter XI.) After this treatment, a fractional distillation is carried out in steam stills. These stills use both open and closed steam coils. Many refiners are also using fires under the still. The steam stills are equipped with dephlegmating towers, so that only the lighter constituents of the crude naphtha can escape. Gravity is relied on by many in making naphtha cuts, but today more and more reliance is being placed on the end boiling point of the fraction. In this distillation, 75 to 80 per cent. of the charge will pass over as commercial grades of gasoline. The residual, known as "naphtha bottoms," is further handled with the kerosene stocks.

Kerosene distillate, as in the case of the naphtha cut, contains products which are not homogeneous. In this case, they are too light and have too low a flash point to be used as burning oils. The distillate is treated in steam stills as before and run down to the desired flash point, as shown by samples taken from the still. The resulting "overhead" (or part distilling



FIG. 3

*(Courtesy Chicago Bridge and Iron Co.)*

Agitators.

over) amounts to about 40 per cent. and is put into the crude naphtha cut from the crude oil distillation, for further handling. The crude kerosene from the still, and the naphtha bottoms above referred to, are then combined for agitator treating. The object of such treatment is to remove color and odor, and also to eliminate unsaturated compounds which would carbonize lamp wicks. After this treatment, the products are the various grades of kerosene oils. If the color is not up to standard, filtering may be necessary.

Gas or fuel oil is usually marketed as obtained, from the

•

crude fire still. It is sometimes blended with heavier oils for producing certain grades of fuel oil. Some refiners subject it to pressure distillation in order to increase their yield of light products. Others divide the fraction, separating the heavier end as soon as wax appears. This is usually done directly from the crude still; or the entire gas oil fraction may be reduced by a second distillation. In either case, the heavier portion constitutes a low grade wax-bearing stock ready for pressing.

Wax distillate is taken from the crude still until the residual cylinder stock shows the desired flash and fire test. This wax distillate contains many compounds of the solid paraffin series, and also the valuable neutral oils from which high-grade lubricants are made. It is again subjected to distillation, this time without the aid of much steam, and as a result is slightly decomposed or "cracked." This changes the character of the wax content from an amorphous to a crystalline form, enabling it to be extracted. The resulting cracked distillate is chilled and pressed as described in Chapter XII, so as to remove the wax therefrom. The temperature of pressing determines the cold test of the lubricating oils made from the pressed oil. The pressed oil is now fire-distilled again, with bottom steam, the residual in the still resulting in a lubricating oil stock. The overhead distillates may be fractionated and redistilled for oils of different viscosities. These, when variously treated and compounded, become the various grades of spindle, automobile, compressor and engine oils of commerce.

The wax taken from the wax distillate is subjected to the sweating process described in Chapter XII. Here the contained oil is removed and the melting point of the wax controlled. After treating to remove impurities, and filtering for color, the commercial paraffin wax is produced.

A chart of the above process (Fig. 4) showing the approximate yields through the various steps, should be of interest.

#### **RUNNING TO COKE.**

This process of distillation is ordinarily employed for those crude oils containing asphalt in quantities which make them un-

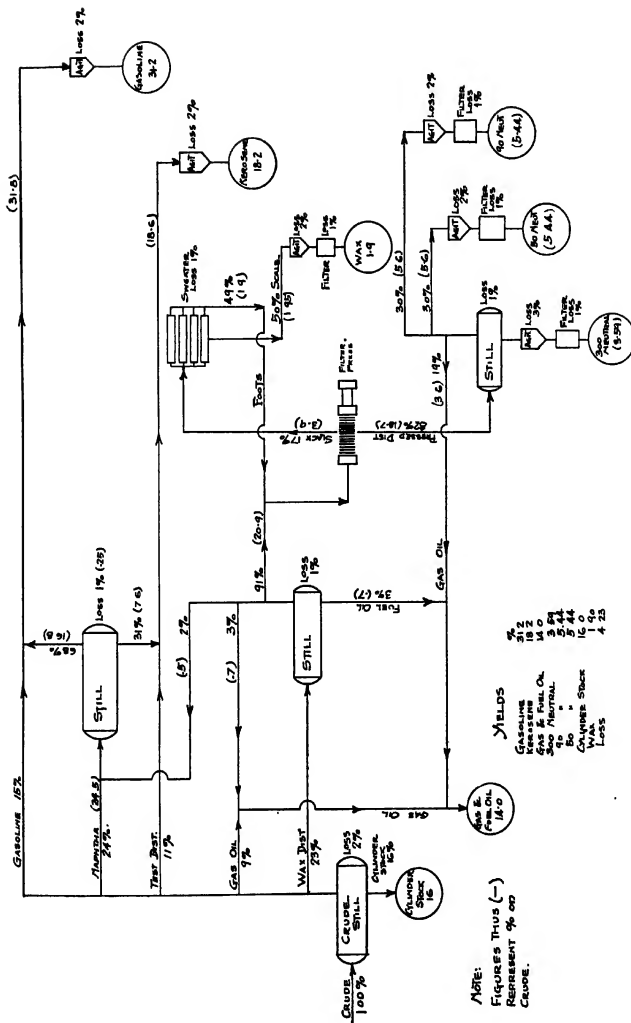


FIG. 4  
Flow sheet, paraffine base oil run to cylinder stock and lubricants.



suitable for cylinder stocks. Cracking is decomposition by heat. The hydrocarbon molecules become unstable with the result that they break down, forming simple molecules of lower boiling point. An attendant result is the formation of fixed gases (gases incapable of later condensation), and carbon. The exact chemical nature of the reaction is not known.

Eliminating the lubricating stocks, the most valuable constituents of a given petroleum are the light products. The cracking method, or running to coke, gives the maximum yield of such products.

The oil is placed in the still as in the case of distillation to cylinder stock, and the fires lighted. In this case, however, bottom steam is used sparingly, if at all.

The typical cuts or fractions are about as follows:

Crude naphtha .....	Start to 47° B.
Kerosene distillate .....	47° B. to 37° B.
Solar oil or engine distillate .....	37° B. to 35° B.
Gas oil .....	35° B. to 25° B.
Residuum or fuel oil	

The crude naphtha and kerosene distillates are further distilled in steam stills or combination stills, using both direct fire and open steam. In this second step, the boiling points, gravities, flash and fire tests are controlled as in the case of similar cuts described in connection with the previous method of running to cylinder stock. The products are then treated as before; but in this case, on account of the partial decomposition in the first distillation, the removal of odors and color may prove more difficult.

Gas oils are sometimes re-run for the removal of the valuable low boiling point constituents which have been formed therein, on account of the high temperature in the still at the time these products were distilling over. Pressure distillation, to further crack the gas oil, is often resorted to, as will be described in a later chapter.

The above outline is typical of the operation of many refineries running on Mid-Continent crudes. The gravities given are

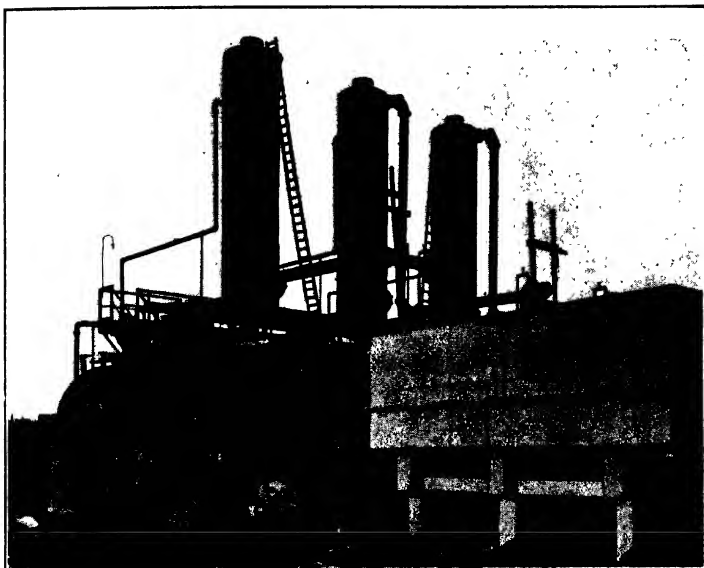


FIG. 5

Steam stills built by the Leonard Engineering Company for the Beacon Oil Co.

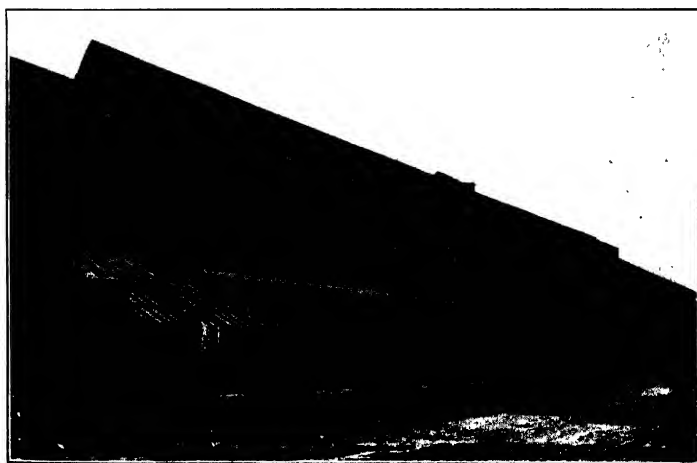


FIG. 6

Modern filter plant of the Tiona Refining Company, at Clarendon, Pa.



representative, but each cut, and especially that of naphtha, is actually determined by the boiling points desired. The gravity is a convenient index of such boiling points, but varies with different crude oils.

It should be noted that the products from a refinery running as described are limited to the following:

- Gasoline, one or more grades;
- Kerosene, one or more grades;
- Engine distillate;
- Gas oil;
- Fuel oil.

Very good lubricants are made by carrying the process further, as follows: (See Fig. 7.)

After the gas oil is taken off, the residual is further run down to solid coke, sometimes in separate stills known as tar stills, but usually in the original crude still. The fractions resulting are

- Lubricating distillate;
- Wax tailings.
- Coke.

The lubricating distillate is the source of the paraffin oils, and (if present in the crude) of wax.

If wax-bearing, the lubricating distillate is chilled and pressed as described in connection with running to cylinder stock. The pressed distillate is treated and further reduced in fire stills with open steam, to realize the required gravity, flash, viscosity, etc., for the lubricating stock desired. If no wax is present, treating, filtering and reduction may be all that are required.

The two general methods described above, with various combinations and modifications, are applicable for refining all grades of crude petroleum. As has been explained, crude oils vary greatly in their physical and chemical characters, and a knowledge of the products available and desired is necessary before the equipment can be properly designed. A few typical flow

sheets for representative crude oils are shown by Figs. 7, 8, 9 and 10.

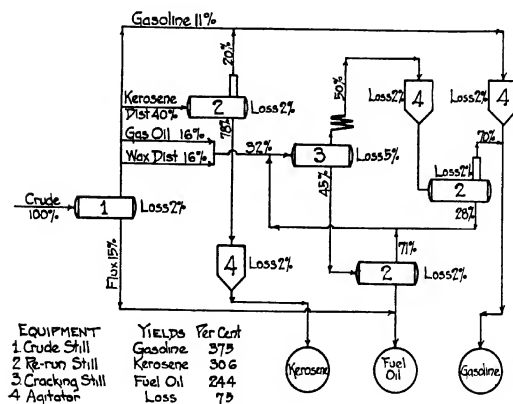


FIG. 8

Mexia crude skimming process with addition of "cracking."

The better known crude oils of this country have been carefully examined, and their physical characteristics and fractional distillation tests are available. An unknown crude oil or one from which new products are desired should be submitted to careful laboratory examination prior to designing a refinery.

To recapitulate:

#### DISTILLATION:

There may be said to be two objects in distillation; the first is to fractionate the crude oil or stock into portions of different gravities and boiling points. While the gravity of the fraction from a particular crude is an indication of its boiling point, it does not follow that similar gravities of fractions from another crude will indicate the same boiling points. The second object of distillation may be either to "reduce" the residual stock in the still, or to raise the flash point. The more light products taken off overhead, the higher will be the flash point of the residual left. In the case of lubricating oils, the viscosity is increased as the stock is "run down." For a given operating

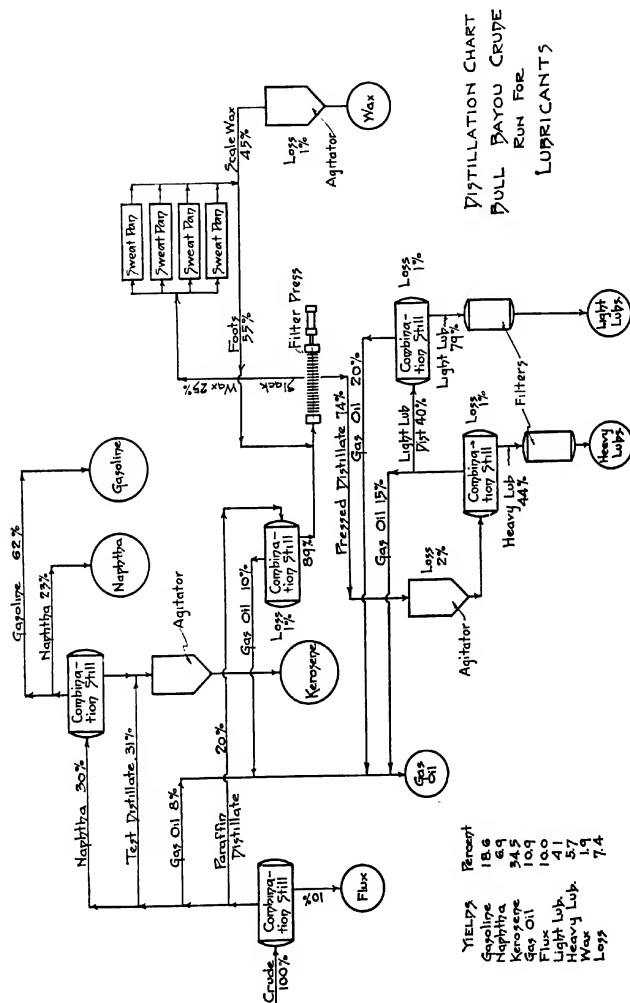


FIG. 9

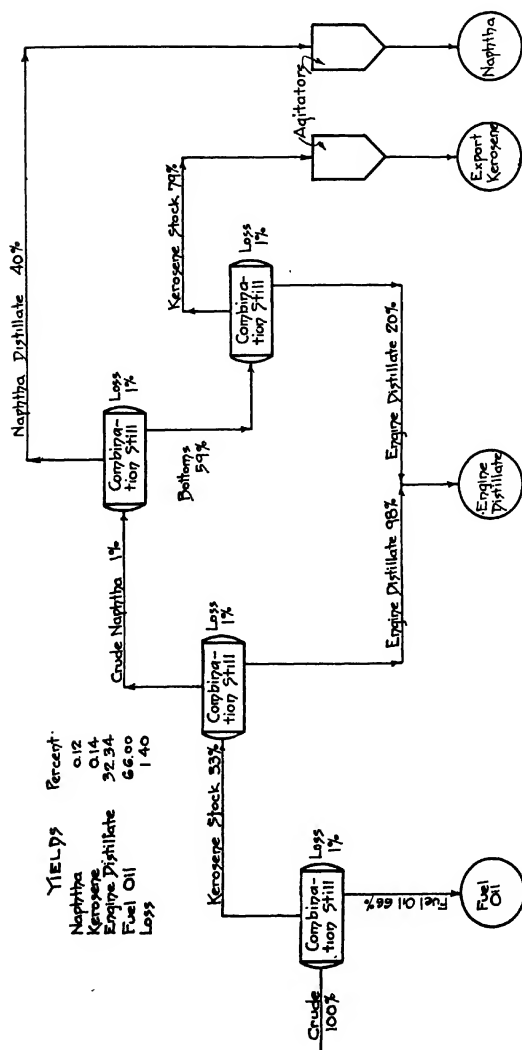


FIG. 10

Flow sheet of typical South Texas crude run to fuel oil.

method applied to a certain crude oil, the gravity and flash point may be inferred from the field tests, which will incidentally indicate the probable residual characteristics. On the other hand, with asphalt, the melting point, ductility and penetration are qualities desired in the residual, and the overhead distillates are of secondary importance.

#### CHEMICAL TREATMENT:

Gasolines and naphthas are treated primarily for color and odor. In both cases the removal of the unsaturated bodies, in part or whole, with sulphuric acid, will produce acceptable products. With high-gravity straight-run gasoline, this step may often be omitted.

Kerosenes receive treatment for similar reasons; but in this case, additional and more serious results would be due to the presence of any unsaturated bodies. It is these compounds that, upon burning, do not completely unite with oxygen and hence give a smoky flame. The sulphur content must also be kept low to prevent wick encrustation.

Again, with lubricants, the unsaturated compounds are detrimental, since they break down more readily under heat, and deposit free carbon.

After any acid treatment, the oil must be neutralized with other chemicals, and afterward these alkalis must be washed out. Air blowing will evaporate the contained water.

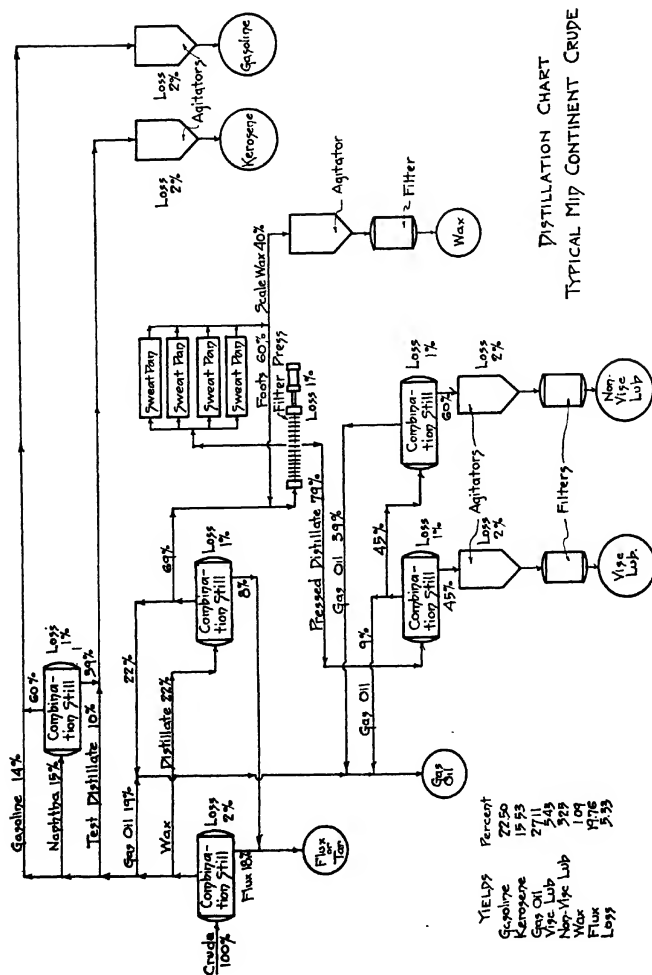
#### PRESSING:

This step is resorted to for the removal of wax from wax-bearing lubricating distillates. The pressing temperatures control the cold test of the resulting lubricating oils.

#### SWEATING:

Wax from the presses contains considerable amounts of oil, which may be removed by gradually heating the wax; a process known as sweating. The temperatures and number of re-sweats govern the melting points of the refined commercial paraffin waxes. •





**FIG. 11**

**FILTERING:**

This process is usually confined to the lubricants and waxes. Only occasionally are the lighter burning oils filtered. The object is to remove color; partly to conform to trade prejudice in favor of light-colored stocks, and also because color is a possible indication of unsaturation.

**COMPOUNDING:**

Various grades of gasoline and naphtha are often blended to improve the distillation range.

Lubricants are blended for viscosities, colors and other qualities. Rarely is a finished lubricant a straight-run product. In addition to the various refinery stocks, other oils, such as rapeseed and lard oil, are blended with the mineral oils.

The various steps outlined above will be discussed more fully in the chapters devoted to the departments in which they occur.

## CHAPTER VI

### THE REFINERY SITE AND GENERAL ARRANGEMENT

Characteristics desirable in the location—Area required—

Physical considerations—Discussion of refinery arrangement.

The location of an oil-refining plant depends on crude supply, markets and freight rates. The proximity of crude supply is often the determining factor in the case of small skimming plants with local markets. For the permanent plant, looking forward to a steady growth, the accessibility of large markets may control the location, and arrangements for transportation of the crude oil. Freight rates on finished products must be balanced against pipe-line and tank-ship charges on the crude supply. These factors will usually determine the general location of the plant. We now turn to a consideration of the site itself.

The ideal site for a refining plant of magnitude should possess the following features:

1. Transportation facilities for crude material;
2. Transportation facilities for finished products;
3. Suitable topography;
4. Good soil for foundation;
5. Ample water supply;
6. Good drainage conditions;
7. Suitable labor supply.

The ideal site may be impossible to attain, but all of the above points should be taken into consideration before purchasing land.

#### TRANSPORTATION FACILITIES FOR CRUDE MATERIALS

Crude oil for the large refineries is usually delivered by pipe line or tank steamer. Tank car deliveries are often relied upon by the smaller plants, and also by larger plants for the receipt

## REFINERY SITE AND GENERAL ARRANGEMENT 75

of partially refined products. We may also class as crude materials such items as coal (if used for fuel), acids and alkalies, fullers earth and supplies of all kinds. It is obvious that rail transportation is important, and a site reached by two or more competing railroads is preferable. If water deliveries are expected, the channel and navigation facilities should be investigated. Tank ships are increasing in size, and a minimum depth of channel of thirty feet at low water is recommended. In northern climates, the records of winter navigation should be investigated. Periods closed to navigation entail a greater investment in crude storage to guard against shut-down.

### TRANSPORTATION OF FINISHED PRODUCTS

Tank cars, tank steamers, barges and packages are all used in the shipping of finished products. Here again, suitable railroad facilities play an important part. Pipe lines have also been used to a limited extent for shipping the lighter products. Most notable among refined oil pipe lines is the United States Pipe Line, running from some of the independent Pennsylvania refineries to the seaboard at Marcus Hook, Pa.

### SUITABLE TOPOGRAPHY

The ideal site is a surface sloping gradually to a navigable stream or bay, if ocean transportation is desirable, or to a lake or river of substantial size. A plot which is roughly square or rectangular lends itself most readily to a proper layout. Railroad facilities entering at the end farthest from the water lead to the most acceptable track arrangement. These conditions are hard to find, especially in the neighborhood of our larger cities. Often, low and swampy ground has to be filled in. When filling, careful observations should be taken to insure a finished grade well above extreme high tide. Many of our older plants are seriously handicapped by neglect of this simple precaution. In rugged country, a careful investigation of flood conditions should be made. A flood in an oil yard may have disastrous consequences.

### GOOD SOIL FOR FOUNDATIONS

Refinery soil loads are, as a rule, very moderate. The loads from tankage very rarely exceed one and one half tons per square foot. Tankage loads form a large proportion of the total. If other features of the site are acceptable, we may, by the device of spreading heavy load foundations, have fairly economical conditions, even on soil with as low a bearing value as the above. A soil of sand, loam and gravel is the best for the future yard surface. This character of soil is usually suitable for all normal loads. Before purchase of a site where the bearing power of the soil is questionable, a sub-surface survey and bearing test should be made. Many thousands of dollars have been lost through failure properly to investigate beforehand. In some cases, the expense of preparing the site and foundations has proved so excessive as seriously to impair the financial success of the undertaking.

### WATER SUPPLY

This subject is one of the most important in determining a refinery site. Quantities required vary with the character of the plant.\* As a general guide, 500,000 gallons of water will be required per thousand barrels of crude consumption, for plants making a complete range of products. For topping plants, with a small amount of re-running, this quantity will be materially reduced. This figure includes the necessary boiler feed water. If the site is adjacent to a considerable body of water, the subject is simplified. Otherwise, water must be purchased, wells driven or a supply piped in. Clean, soft water will of course be required for the boilers, and also for treating, as hereafter discussed. After obtaining this necessary clean supply, which may be taken as 30 per cent. of the total amount required, it is common practice to obtain the balance from any source available, paying little attention to quality. If it is impossible to secure the total amount required in good, cold water, this course is permissible. The 70 per cent. of low grade water thus obtained is used only for condensers, fire-fighting and general pur-

\* See Chapter XXII.

## REFINERY SITE AND GENERAL ARRANGEMENT 77

poses. It should be noted, however, that this expedient will involve a double water pipe line system throughout the yard. In locations where water is scarce, cooling towers have been resorted to. These are expensive, and this method should be compared carefully with the cost of more cold water if it is possible to obtain it by any means whatever.

### DRAINAGE CONDITIONS

Aside from the usual problem of disposing of rainfall, the refinery engineer must take into consideration the disposal of a large amount of condenser water and refinery waste. This waste, from unavoidable mishaps, often carries slop oils and chemicals. Stream pollution is liable to follow. For this reason, ejection into small streams should be avoided. The public attitude is often narrow on this point. Many streams already foul, after further pollution, however slight, are remembered in the public mind as water ways of previous extreme purity and beauty. Neighboring civic and manufacturing water requirements should be investigated, and state boards consulted, before using a stream for waste disposal.

### SUITABLE LABOR SUPPLY

Oil refining is often centered in well-defined localities. There are familiar examples at Bayonne, N. J., in the Philadelphia district, at Warren, Pa., and at Tulsa, Okla. In such communities, the problem of obtaining employees skilled in process work is simplified. The process worker is usually settled and reliable, the labor turn-over being greatest in the maintenance crews and common labor gangs. It is therefore advisable to bear in mind the mechanic and common labor supply rather than the process worker, in considering refinery location. The supply of men for these kinds of work is greatest in or near large cities. It is true that the labor turn-over in these districts will probably be greater than in a plant located in the country. Many companies in isolated localities have erected houses for employees. This is an item which should receive due consideration in connection with the selection of a site.

## AREA REQUIRED

No set rule can be applied to all plants, on account of the various stages to which the refining process is carried. We may, however, evolve some approximations from which a fairly accurate estimate may be made of the amount of land required.

A refinery depending on railroad or water delivery of crude should have available in storage a minimum of three months' supply of crude oil. One located at the wells or on a pipe line may reduce this to two months'. Crude storage provided in accordance with Underwriters' requirements amounts to 9,500 barrels per acre if 55,000 barrel tanks are used; or to 11,200 barrels per acre, using 65,000 barrel-tanks. Many companies exceed this amount by twenty to twenty-five per cent., paying a higher premium, if insurance is carried.

Finished stock storage to take advantage of market conditions should not be less than three months' yields. Note, however, that the refining loss and coke are eliminated. Lubricating stock and wax tanks may also be grouped more closely than crude oil tanks. With this reduction, twenty to twenty-five thousand barrels of tank storage per acre is a fair figure.

Complete refineries, running to all products, with acid recovery, shops, case, can and barrelling departments, will occupy ten to twelve acres per thousand barrels per day of throughput, exclusive of storage space for crude and finished stocks.

Skimming plants will occupy about five acres per thousand barrels. The land necessary for plants more nearly complete, but not finishing up all products, will be somewhere between five and ten acres per thousand barrels daily. The figures for the refinery will include the intermediate stock and working tanks.

As an example of these figures, let us compute the acreage requirement for a complete refinery of 10,000 barrels per day capacity, located on a reliable pipe line:

	Acres
2 months' supply, 600,000 bbl. of crude at 11,200 bbl. per acre,	54
3 months' yield, 810,000 bbl. finished stocks at 24,500 bbl. per	
acre, .....	33
Refinery proper at 12 acres per 1,000 bbl. daily. ....	120
Total .....	207

## REFINERY SITE AND GENERAL ARRANGEMENT 79

The above figures are based on using 65,000 barrel crude tanks and on 10 per cent. loss and coke.

The ideal layout provides crude storage on one side of the plot and finished stock storage on the opposite side, with a continuous flow of stocks directly through the refinery. If finished products are to be shipped by water, the compounding and barrelling departments should be located between the finished stock tanks and the dock. These requirements are often hard to meet on account of topographical conditions, and the entire problem should receive careful study to eliminate the pumping of stocks back and forth.

The heart of every plant is its power and boiler house. Modern practice is in favor of the central boiler plant. Some of our largest and most famous oil refineries are abandoning their

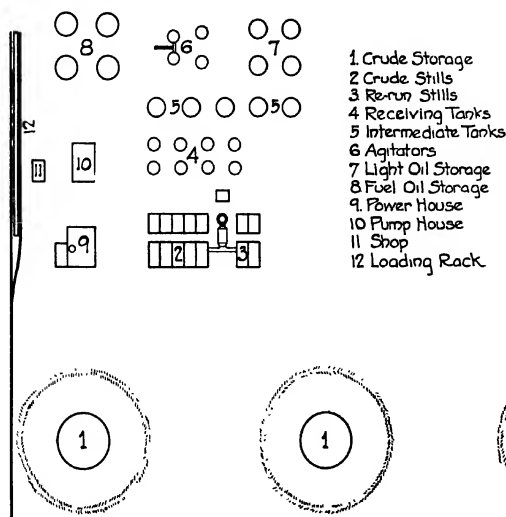


FIG. 12

General arrangement of 5000-barrel skimming plant.

several isolated boiler houses, the outcome of haphazard growth, and concentrating boilers and power equipment. Such power plant should be placed as near to the center of steam and power



distribution as is possible. The shops, storehouse and laboratory, for general convenience, should also be near the center of the refinery proper.

Future expansion of the plant is a matter which should be carefully considered. A refinery in which this important point has been overlooked is often seriously inconvenienced in operation after extensions have been made, to say nothing of the excessive cost of such extensions. A good precept to follow is

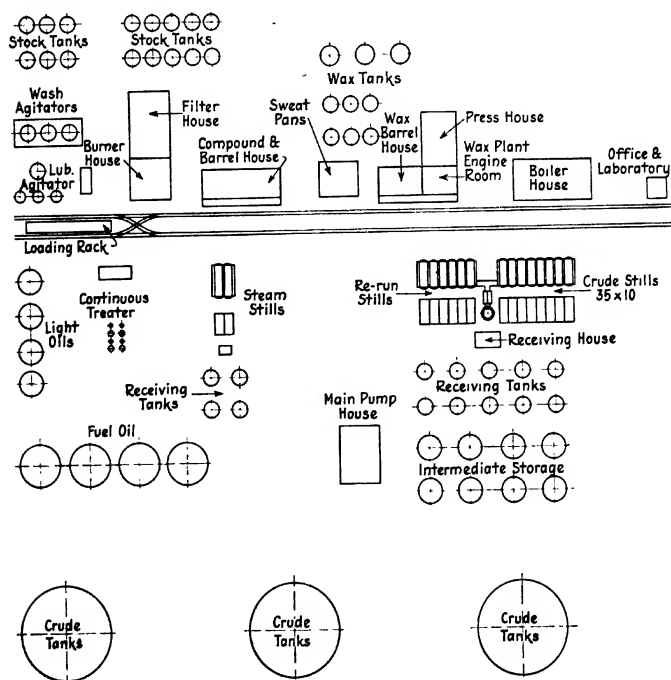


FIG. 13

General arrangement of small lubricating refinery.

to design for the maximum plant any probability of which can be foreseen. The departments should be arranged so that the original installations will be adjacent and compact, and may then grow outwardly. It is a mistake to space departments far apart in anticipation of future growth, and then to grow in-

## REFINERY SITE AND GENERAL ARRANGEMENT 81

wardly. Long pipe lines and increased operating cost, with a higher initial investment, result inevitably.

A few suggestions as to individual departments may be of interest. The refined oil department, which is devoted to the treatment of gasoline and kerosene, should, on account of the attendant dangers, be isolated sufficiently to eliminate risk to the balance of the plant. The acid recovery plant should be adjacent to the department where lubricating oils are treated,

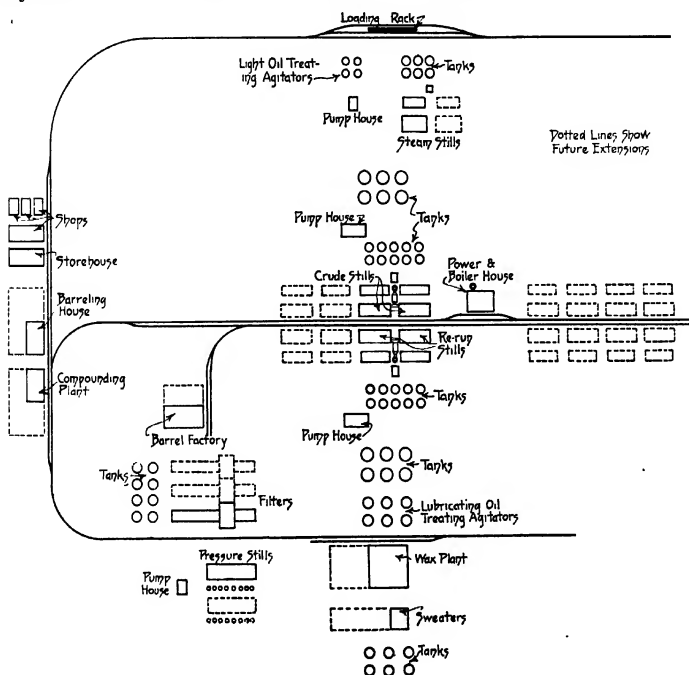


FIG. 14

General arrangement of large complete refinery of 10,000-barrel initial and 40,000-barrel ultimate capacity.

since the bulk of the sludge acid comes from those departments. The acid plant, on account of the objectionable fumes, should be to the leeward of the refinery proper, as far as the prevailing winds are concerned. Pressure stills, if installed, should be isolated in the same way, as the refined oil department.

A few typical layouts will now be discussed.

Fig. 12 shows a small skimming plant of 5,000 barrels per day capacity. This layout is easily extended. The stocks flow from storage to crude stills, to re-run stills, to treating, to storage, to loading, all without interference. The arrangement is flexible, in that if distillates are to be treated prior to re-running, a slight modification of pipe lines will suffice. The power house is centrally located for steam distribution, and the office, laboratory, stores and shop are central to the major part of the work.

Fig. 13 shows a small complete refinery of about 4,000 barrels capacity.

The arrangement of a refinery of 40,000 barrels per day ultimate capacity is suggested by Fig. 14. This layout is based on a complete line of products. Pipe line and tank ship are used for crude deliveries, water and rail for shipping. An initial installation for 10,000 barrels is shown in full, the ultimate development being shown dotted. Although arranging the layout for 40,000 barrels, the various departments may be started in a small way and kept compact and adjacent.

All of these are typical layouts on ideal sites. Many modifications for plants of intermediate size and varying topography may be suggested. The various illustrated arrangements suggest the influence both of the crude oil to be run and of the products desired. No attempt has been made to deal with the capacities of the various pieces of apparatus and equipment, as this subject will be touched upon in detail in later chapters.

## CHAPTER VII

### STILLS

General discussion—Types of still—Specifications—Setting  
—Tube, steam and vacuum stills—Efficiencies.

In other than tube stills, the principal factors which control the rate of distillation are,

- The evaporating surface;
- The heating surface;
- The area of the vapor outlet.

The *evaporating surface*, for the usual type of horizontal cylindrical still, may be taken as  $\frac{2}{3}$  of the diameter multiplied by the length, when the still is operated on the batch principle. The factor  $\frac{2}{3}$  will allow for reduction in area of the evaporating surface as the oil level drops in the still. An analysis of the records of many still runs shows the amount distilled or "taken overhead" to vary between 1.27 and 1.71 gallons per hour per square foot of evaporating surface, with the average at 1.50. This figure allows 6 per cent. of idle time for charging, pumping out, etc., and may therefore be used directly for estimating the operating results over an extended time or for designing new equipment. When a battery of stills are arranged to run continuously, the above rate can be greatly increased. Records are available showing the gallons per hour per square foot of evaporating surface to be between 2.5 and 3.3. The lower figure of 2.5 is recommended for calculations involving continuous distillation. In the case of continuous stills, the oil level can be maintained near the half diameter, so that the factor of  $\frac{2}{3}$  need not be applied to the actual surface, which is simply the length times the diameter.

The *heating surface* must of course be ample to transfer sufficient heat to effect the distillation. In the case of continuous stills, the full half circumference is often fired. Records of such

stills show that 2.5 gallons of distillate per hour per square foot of heating surface may be depended upon. With batch stills, the area of bottom exposed to the furnace gases is usually reduced, to avoid the possible exposure of a portion of the bottom to the action of the flue gases on one side without any oil to conduct the heat away on the other. This condition would arise as the oil level dropped, unless the protecting walls of the setting were drawn in toward the still center. Usually one third of the circumference is exposed to the heating medium under such conditions. In this case, however, the rate of evaporation is slower than with the continuous system, so that the amount of distillate is not limited by the area of heating surface, provided that the still is exposed to the furnace gases for its entire length, excepting only for the front and rear furnace walls.

The *area of the vapor pipe* must be sufficient to permit free and unrestricted passage of the oil vapors and free steam (if used), to the condensers, at a rate sufficiently high to accommodate the full still capacity, as determined by the preceding factors. From observation of stills of various dimensions with various areas of vapor outlets, a standard of not less than 0.17 square inches for each gallon of overhead distillate per hour is suggested. This area will be sufficient to carry away oil vapors and steam without objectionable back pressure at the rates previously given.

TABLE 32: HORIZONTAL CYLINDRICAL STILLS  
DIMENSIONS AND CAPACITIES

Charging Capacity, 42 Gal. Barrels	Total Capacity, 42 Gal. Barrels	Dia., Feet	Length, Feet	Vapor Pipe Dia., In.	Evaporating Surface, Sq. Feet	Gals. of Distillate per Hr., at 1.5 per Sq. Ft.	Gals. of Distillate per Hr., at 2.3 per Sq. Ft.	Estimated Weight, Lb.
180	214	8	24	8	128	192	294	16,800
350	416	10	30	10	200	300	460	24,600
615	725	12	36	12	288	432	662	41,800
1,000	1,150	14	42	14	392	588	902	56,000
1,200	1,416	15	45	15	450	675	1,035	65,700

Generally speaking, the horizontal cylindrical stills most in favor have a length of approximately three times the diameter.

The vapor outlet is generally placed from half to two-thirds the distance from the fire box end to the rear.

Based on the preceding discussion, Table 32 of horizontal cylindrical still dimensions and capacities is offered.

Specifications for the construction of stills of this type should be drawn to suit the service in which they will be used. Fig.

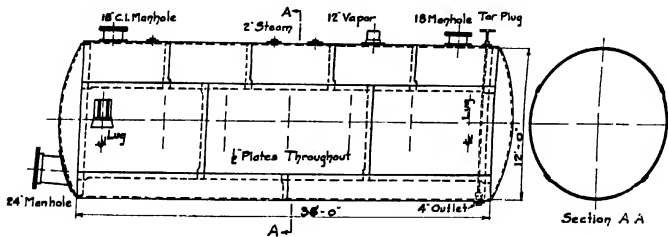


FIG. 15

600-barrel fire still.

15 shows the plate arrangement usually adopted for a direct fired still. The bottom is of steel of "fire box" or "still bottom" quality. The section shows how the caulking edges of the bottom plates are kept away from the furnace gases. This is most important. The thickness of the bottom plates is usually  $\frac{1}{2}$  inch. It is well established that the thinner plates lead to higher maintenance costs, because when heated, they will bag and buckle quicker and burn out sooner. On the other hand, thicknesses over  $\frac{1}{2}$  inch for ordinary still bottoms are not recommended, on account of higher first cost and increased difficulty of patching. For very severe service, as in stills running down to coke,  $\frac{5}{8}$  inch bottoms have proved economical. For stills up to and including 10 feet diameter,  $\frac{3}{8}$  inch flange steel for side and top plates is satisfactory. Larger stills should have  $\frac{1}{2}$  inch shell plates throughout.

The arrangement of seams should be carefully analyzed. Referring to Fig. 15 the bottom is of two plates and the sides of three, while the top is of comparatively narrow "barrel"

plates. This construction is well adapted to stills up to 30 feet long. When longer, it is usually advisable to make up the bottom in three plates, the sides in four and the top of barrel plates, five to six feet wide. The reason for this construction is to reduce the number of seams in the bottom and sides and at the

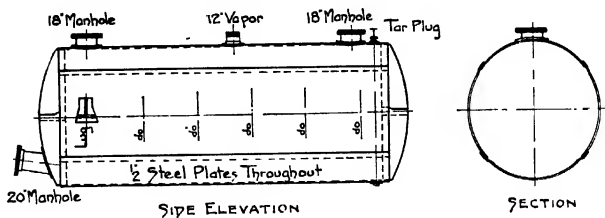


FIG. 16

Plate arrangement of fire still to eliminate girth seams.

same time to keep the plate lengths within the capacity of the bending rolls of the usual fabricating shop. Some companies have gone to the extreme of making up the shells of stills in four pieces without girth seams, as in Fig. 16. Construction of this type is expensive, as the plates must be pressed

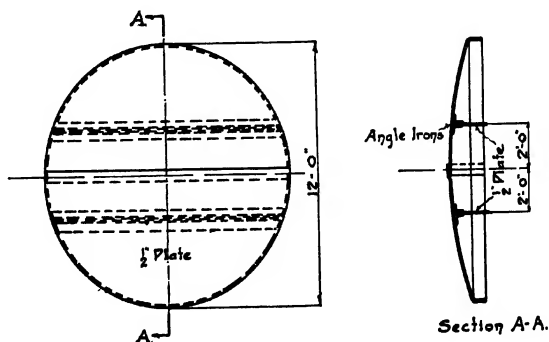


FIG. 17

Still head braces.

and hammered to shape in all shops except those equipped with unusually wide bending rolls. For batch or coking stills, it cannot be recommended, as the bottoms will burn out just as

quickly and after some patching must be replaced. The expense of such replacement is necessarily greater than if there were one or two girth seams. Then too, it is usually the front plate that goes first, and often replacement of this one section will suffice to keep the still in service. For continuous stills, or stills topping only part of the charge, this construction may be warranted.



*(Courtesy Hammond Iron Works.)*

FIG. 18

Fire still, shop assembled, ready for riveting.

The heads are usually dished to a radius equal to the diameter; those ten feet in diameter and under may be in one piece, while those of larger size have a seam on the horizontal diameter. Heads are usually made equal to, or  $\frac{1}{16}$  inch greater in thickness than, the side and top plates. Plate and angle stiffeners are sometimes used in the larger heads (Fig. 17).

The still should be double riveted on all seams except at flange and detail openings. The extra cost is slight and is well repaid by the extra stiffness. The additional insurance against leaks is also advantageous. The design of joints is not determined by the joint efficiencies. Tightness and ease of replacement of plates are the controlling factors. For the latter reason,  $\frac{3}{4}$  inch rivets



are recommended even for the heavy bottom plates. Then, when necessary in case of repairs, the holes may be reamed to  $\frac{7}{8}$  inch

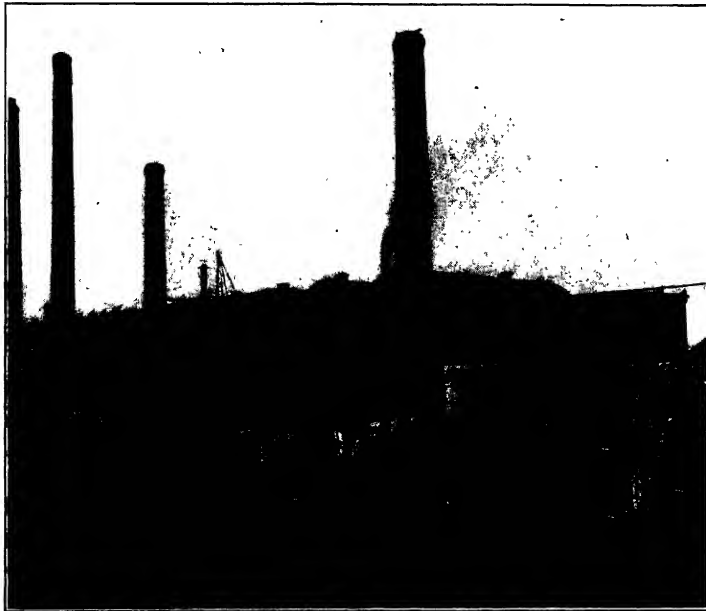


FIG. 19

(Courtesy Hammond Iron Works)

Battery of ten fire stills under construction.

and often to 1 inch. Still riveting as follows has proved very satisfactory:

Plate, In.	Rivet, In.	Pitch (Double), In.	Gauge, In.	Edge Distance, In.
$\frac{5}{8}$ "	$\frac{3}{4}$ "	3"	2"	$1\frac{1}{4}$ "
$\frac{7}{16}$ "	$\frac{3}{4}$ "	3"	2"	$1\frac{1}{4}$ "
$\frac{1}{2}$ "	$\frac{3}{4}$ "	$3\frac{1}{8}$ "	$2\frac{1}{8}$ "	$1\frac{1}{8}$ "

Plates of stills should be beveled and caulked inside and out. The extra expense is well warranted by freedom from leaks during the early life of the still. Details of steel should be beveled and caulked to the shell and the shell opening shipped

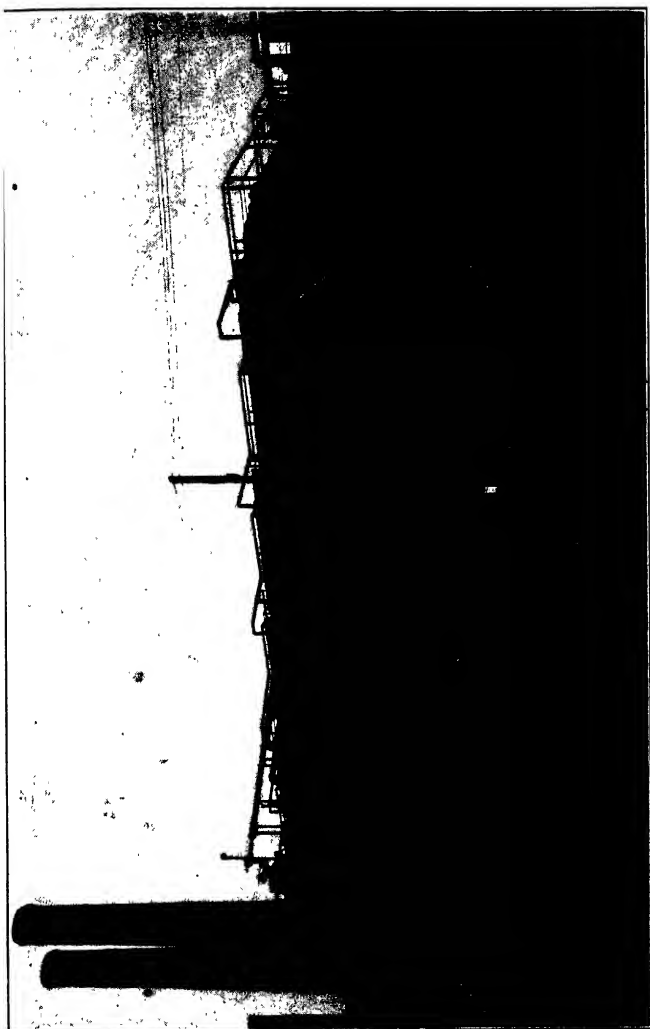


FIG. 20  
Continuous topping stills, Beacon Oil Co., Everett, Mass.

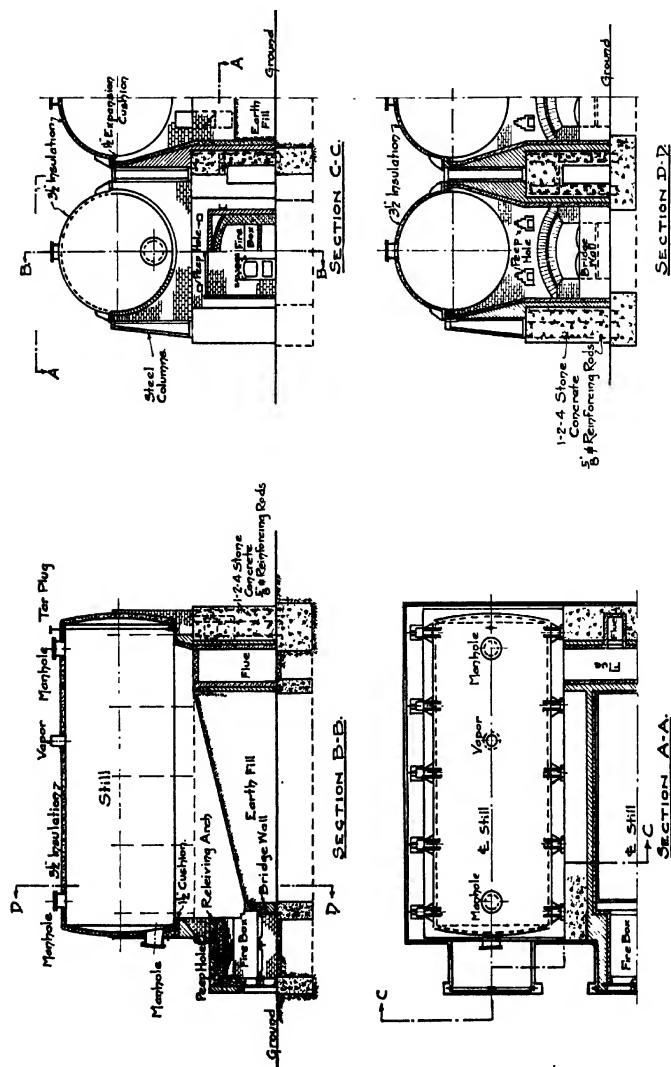


FIG. 21

Concrete and brick setting for fire stills.

and caulked to the detail. Cast iron details should be provided with a caulking pad and treated as above.

A modern setting for a 600 barrel still is shown in Fig. 21. The still is suspended on lugs from columns resting on the concrete piers and thus independent of the brickwork. Lugs should be spaced not to exceed seven feet to keep the still in proper alignment. The lug bearing is on the tip, several inches from the still. This reduces the brickwork to a minimum, and allows the columns to remain exposed to the air. When it is desired to run continuously, the lugs are sometimes raised 12 inches above the horizontal diameter, thus enabling the brickwork to be so designed as to expose the full half circumference to the furnace gases. When the lugs are so raised, it is necessary to introduce a horizontal tie of a stiff structural shape between them to keep the still in shape (Fig. 22). The lug detail is so designed that the rivets of the clips of the stiffener pass through the shell plates only. The reason for this construction is to avoid carrying rivets through three thicknesses of metal, a construction very difficult to make oil tight. Buck stays are avoided in this type of construction by utilizing the column bracing to maintain the brick work in line.

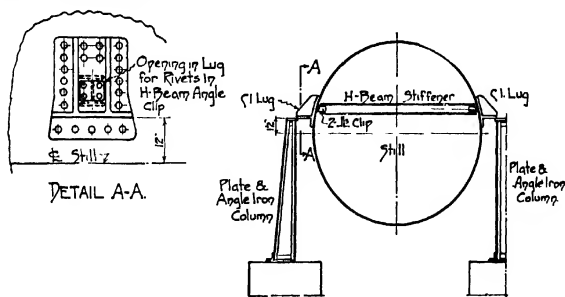


FIG. 22

Columns, lugs and stiffeners for fire stills.

For many years, oil refineries were almost a public nuisance on account of poor combustion and resulting smoke. One of the principal factors producing this condition was the practice

of placing the stills too close to the grates. Often only three or four feet were allowed from grate to still bottom. To insure better combustion, stills should be set at a minimum of seven or eight feet above the grates or burners. When set low, the gases will strike the relatively cool still bottom prior to complete combustion, with resultant poor efficiency and smoke. A still better arrangement is to draw the fire box out into a Dutch oven in front of the setting proper. This construction is illustrated by Fig. 23.

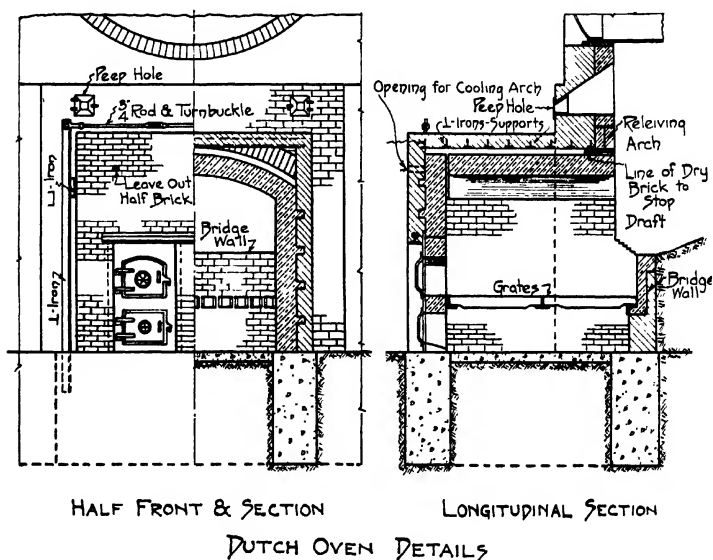


FIG. 23

Details of Dutch ovens for coal-burning stills.

When running oil to coke, it was for many years considered necessary to have the stills side fired in order to insure an even distribution of heat. The stills were set in pairs with the setting arranged as in Fig. 24. On account of the short passage of the gases, the efficiency of such a setting is very low. Recently, with properly designed furnaces, it has been found that equally

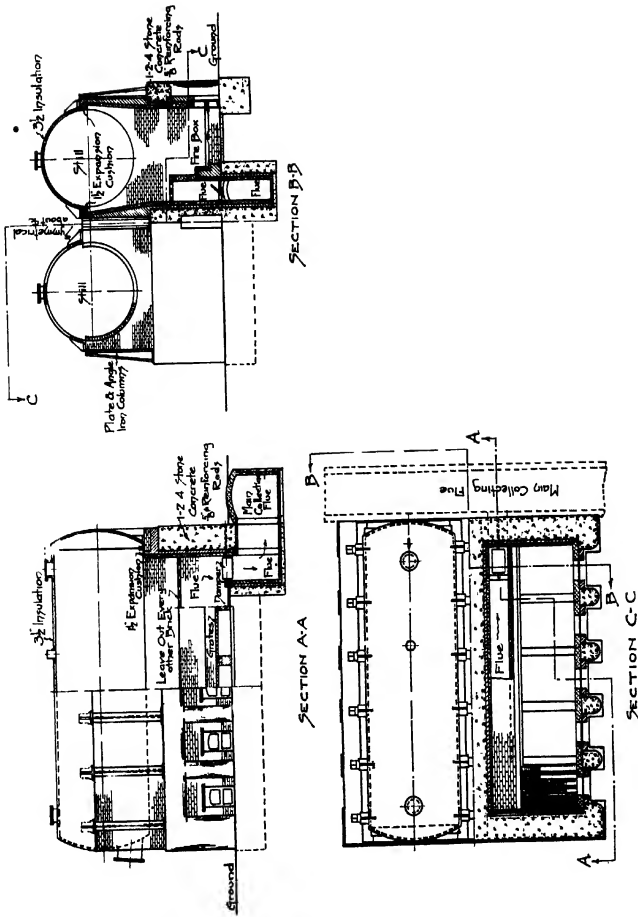


FIG. 24

Side-fired setting for coking stills.



*(Courtesy of C. B. Roberts Eng. Co.)*

FIG. 25

End fired coking stills at the Fall River refinery of the New England Oil Company.

good operating results can be attained by end firing, with economy of space and operation.

A detail of setting worthy of attention is at the points of contact between still and brickwork. Provision for still expansion

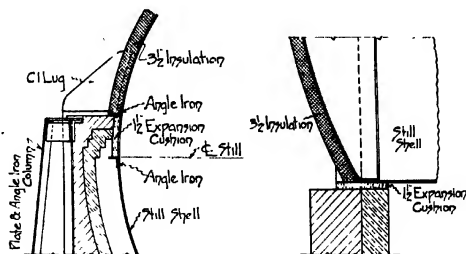


FIG. 26

Still-setting details.

without damage to the brickwork is necessary. Between the end furnace walls (which should be back of the head-to-shell rivets for application of the insulation), a pad of  $\frac{1}{2}$  inch thick asbestos "roll fire felt" will act as a cushion and preserve the brickwork. The same material placed between the furnace longitudinal walls and the still will absorb the lateral expansion. This layer should be 1 inch thick and may be held in place by small angles fastened to clips riveted to the shell. Fig. 26 illustrates these details.

The arches of Dutch ovens should be free from the face wall to avoid cracks. Various patented suspended flat arches have been used in this service with success.

Fire brick linings for the combustion chamber and front third of the still should be of good quality, 9 inches thick and well bonded to the common brick backing;  $4\frac{1}{2}$  inch thickness will suffice for the rear setting and flue linings.

A popular flue arrangement is shown by Fig. 27. This may be proportioned as in boiler practice, with an allowance of 10 per cent. additional area on account of the higher temperature of the outlet gases. Underground flues should be avoided if possible. Their only advantage is appearance and unobstructed



passages. Besides their extra first cost, they are a source of danger. They are difficult to drain, and in case of fire may par-

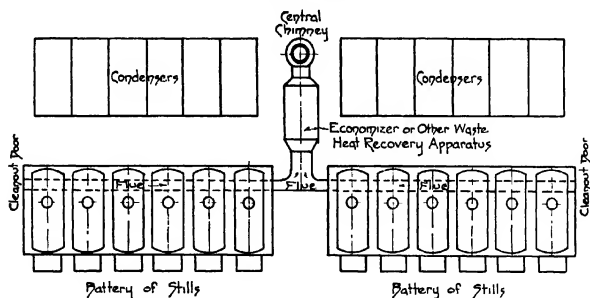


FIG. 27

Flue and chimney arrangement for twelve-still battery.

tially fill with water from fire streams. Under this condition, burning oil may be carried by them to other stills and constitute a serious menace.

Continuous methods of operating stills are much to be preferred if the quantity of oil is sufficient. The number of stills will depend on the number of cuts and on how far the oil is reduced. Usually six to eight stills are arranged in a continuous battery. Each still is placed about 6 inches below the preceding one, assuring a gravity flow through the battery. The volume of distillate from each still will range from eight to twelve per cent. of the throughput. Fig. 28 illustrates the flow line arrangement on such a battery. If the oil is to be reduced to a definite test on the residual, it is customary to transfer continuously from the last continuous still to two or more batch stills for completing the distillation. In this way the efficiency of the continuous method and the absolute control of the batch still are combined. Continuous distillation lends itself admirably to all phases of heat exchange, a given investment in equipment gives a greater throughput, there is less wear and tear on stills and settings, and there is obtained a better efficiency, both of fuel and of labor.

Another type of still preferred by some refiners is the verti-

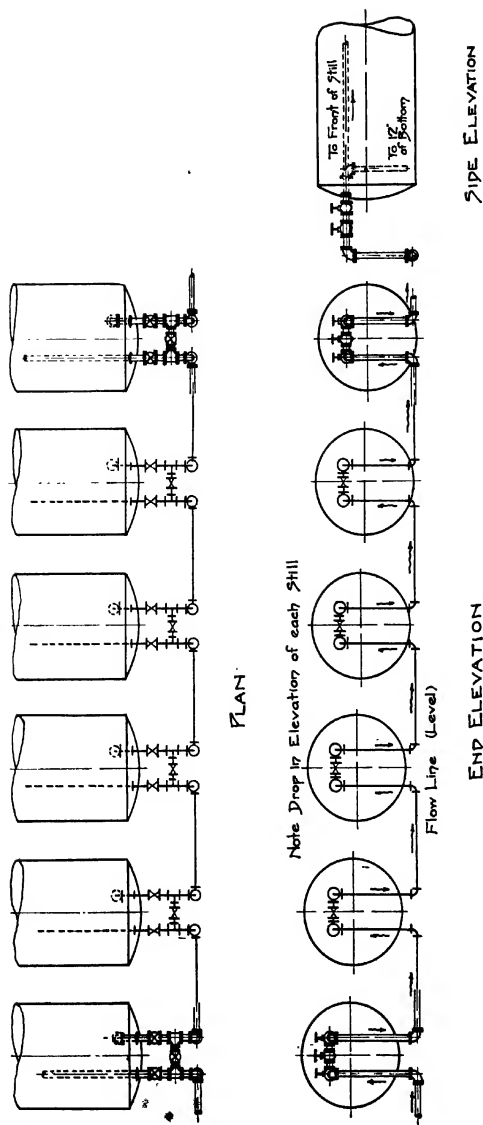


FIG. 28  
Flow line for continuous stills.

cal cylindrical or "cheese-box" still of Fig. 29. These stills are in use in all sizes, up to 1,200 barrels' charging capacity each. The argument advanced in their favor is solely based on the

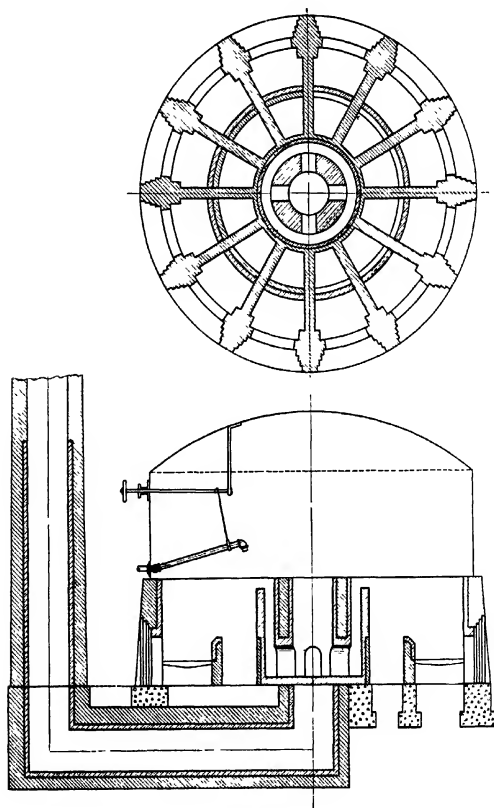


FIG. 29

"Cheese box" still with conventional setting.

claim of superior quality of products. This is probably accounted for by the constant evaporating surface and constant ratio between that surface and the heating surface. These factors might make the control of the still better than that of a horizontal still. There can be no question, however, that the

efficiency of the cheese-box type is low. The heating surface, set as it must be over brick walls to support the bottom, is small, and the travel of the furnace gases short, two obvious reasons for inefficiency.

A type of apparatus for distillation which is attracting attention to-day is the tube or pipe still. Originally designed for dehydrating heavy crude oils, the low cost and high efficiency have led to further developments until it is now used for a great variety of work. The modern tube still consists of a continuous coil of pipe set in a chamber for the application of heat. The coil discharges into a chamber of considerable volume termed the separator. Here the vapors evolved during heating are released and led to condensers of various types. Fig. 30 is dia-

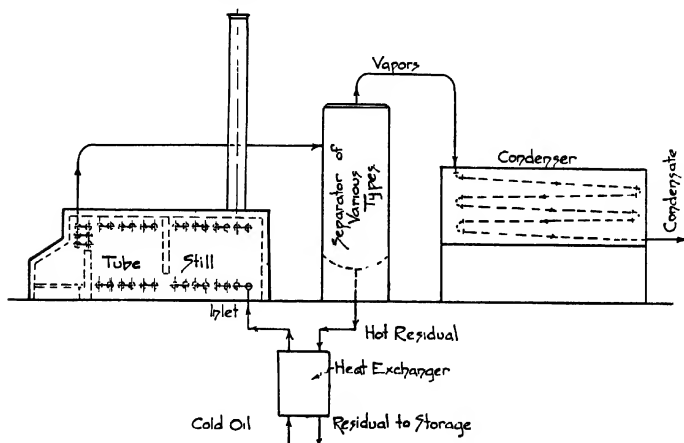


FIG. 30

Diagram of tube or pipe still.

grammatic of a typical tube still. It is obvious that the vapors leaving the separator are composed of several of the "cuts" possible on an ordinary still. To effect separation into final products, fractional condensation must be resorted to. It is difficult to obtain close cuts by condensation, and some criticism has been directed at the tube stills for this reason. The fuel

efficiency (as later discussed), cost and labor requirement are all favorable, and for topping service this type of still is admirable. Some refiners take off further cuts, such as kerosene and gas oil, with this apparatus, and express satisfaction.

One of the troubles with earlier designs was a deposit of carbon on the interior of the tubes, resulting in overheating of the tube walls, and sometimes in rupture. It is now generally conceded that a high tube velocity will eliminate this trouble and carry the carbon, suspended in the oil, into the separator; to be removed with the residual. This velocity should not be less than 3.8 feet per second. As the coil is continuous, the pipe size is in itself a deciding factor in the throughput. At the velocity above given, the recommended capacities of tube still units in barrels of throughput per day are as follows:

2 inch—1,200;	4 inch— 5,000;
3 inch—2,700;	6 inch—10,500.

With the capacity fixed by the pipe diameter, the amount of distillate possible to take off "overhead" will depend upon the heating surface and therefore upon the length of coil exposed to furnace gases. Best results, as far as maintenance is concerned, are obtained with moderate combustion chamber temperatures, of about 1,500° F. For such conditions the charts of Fig. 31 are submitted to show the amount of surface per barrel per day, to allow for various percentages of throughput taken off as distillate.

The separator may be horizontal or vertical, but must have ample capacity to permit a free escape of vapors. From 2½ to 3 cubic feet per barrel of overhead distillate per day should be allowed. The vapor outlet from the separator should have an area of not less than 0.13 square inch for each barrel of overhead distillate per day.

A tube still of 5,000 barrels' capacity per day, designed to take 25 per cent. of distillate from the crude, is illustrated by Fig. 32.

Tube still practice is generally open to all. The best known patented apparatus of this type is that of the Trumble-process,

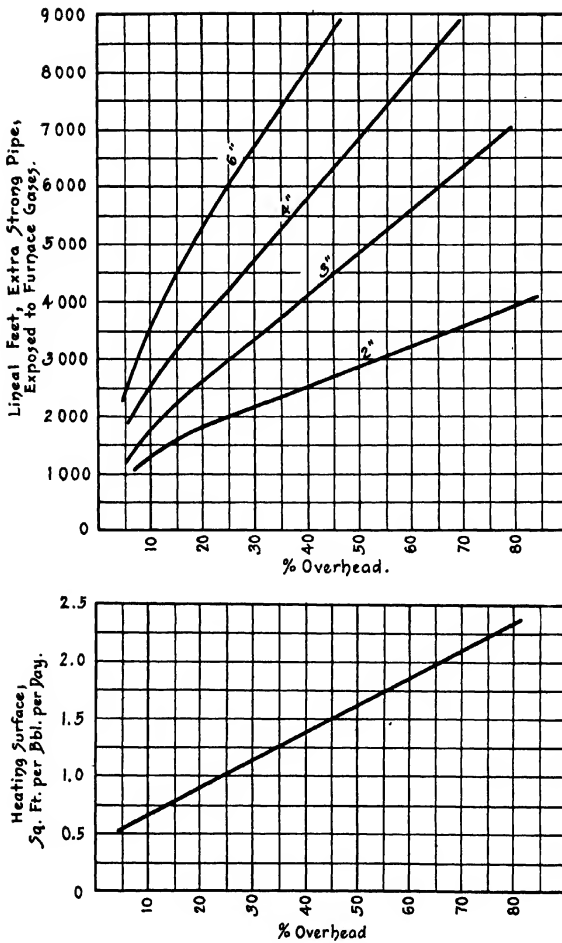


FIG. 31

Chart showing surfaces and lineal feet of pipe required for tube stills removing various percentages of "overhead" distillate.

U. S. patents 996736, 1002474 and 1070361. The novel features of this apparatus are the separator and the elaborate fractionating and condensing system. The separator, of the vertical

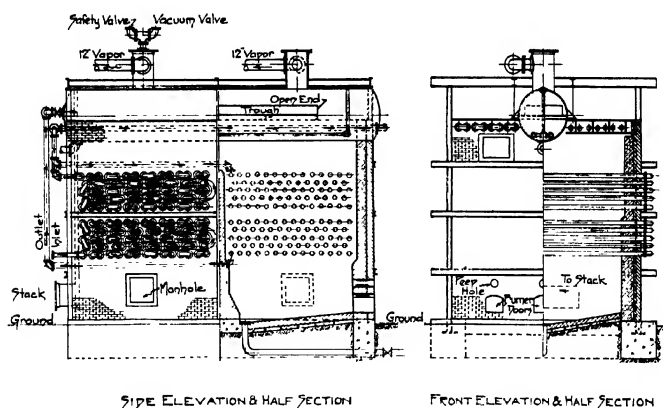


FIG. 32

Tube still for 5,000 barrels' daily capacity.

type, is enclosed in a brick chamber; and waste gas from the retorts is passed over it. The vapors are collected under the cone-shaped baffles into a vapor pipe concentric with the shell, and pass hence to a vapor header on the outside of the brick chamber. Fig. 34 gives a general view of the retorts and separators.

The familiar Foster steam superheater element is well adapted to tube still construction. A section of a Foster still is illustrated by Fig. 35. The arguments advanced in its favor are the large amount of heating surface per lineal foot of element, due to the cast iron fins incasing the tube proper, and the ability of the large amount of heated iron to compensate for variations in firing, thus insuring steady operation.

From this description of tube stills, it is apparent that their field lies in topping only, or for reducing those crudes where a cracked residual is not objectionable. The temperatures to which the oil is subjected are high and there is no opportunity

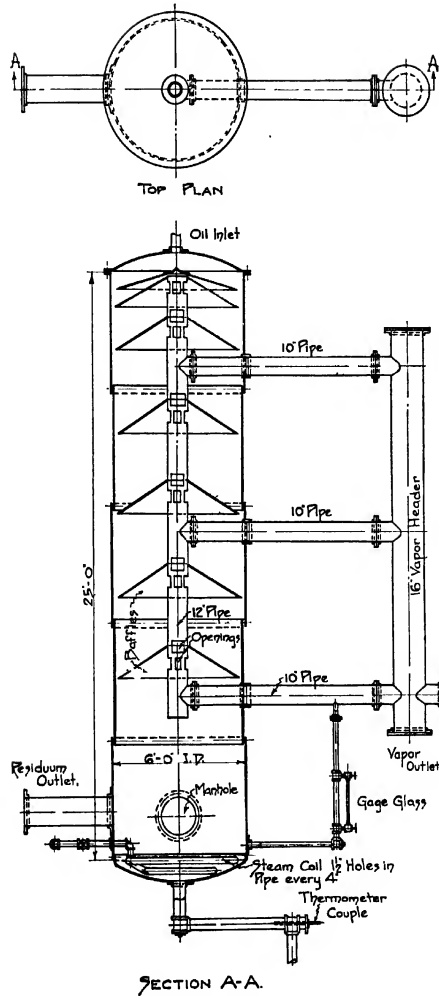


FIG. 33

Separator for the Trumble system of distillation.



for the introduction of bottom steam; hence they cannot be recommended for high class lubricating residuals.

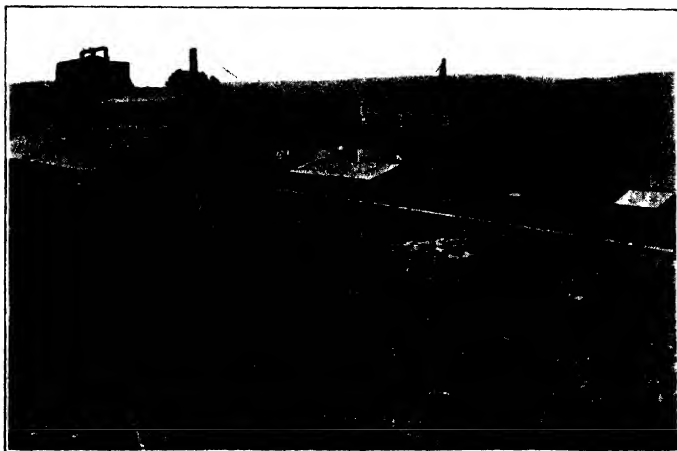


FIG. 34

Installation of Trumble system in the Martinez refinery of the Shell Company of California.

Retort and separators at left, dephlegmators and condensers in center background, pump house in center and receiving house at right. Capacity 7,000 barrels per day with 15 per cent. overhead.

In the earlier days of refining, so-called steam stills were largely used in re-running naphtha and kerosene stocks; the former, to obtain commercial gasoline, and the latter to bring burning oils to the proper flash point. This work is largely done today in combination stills, using the open steam sprays of the usual steam stills, but mounted over combustion chambers similar to those previously discussed. The arguments advanced are, economy of operation, with respect both to time consumed and to heat efficiency.

Many, however, still prefer the "all steam" still, particularly for removing naphtha from lubricating stocks filtered or settled in solution. Steam still construction may be quite different from that for fire stills. Originally it was the custom to put hemi-

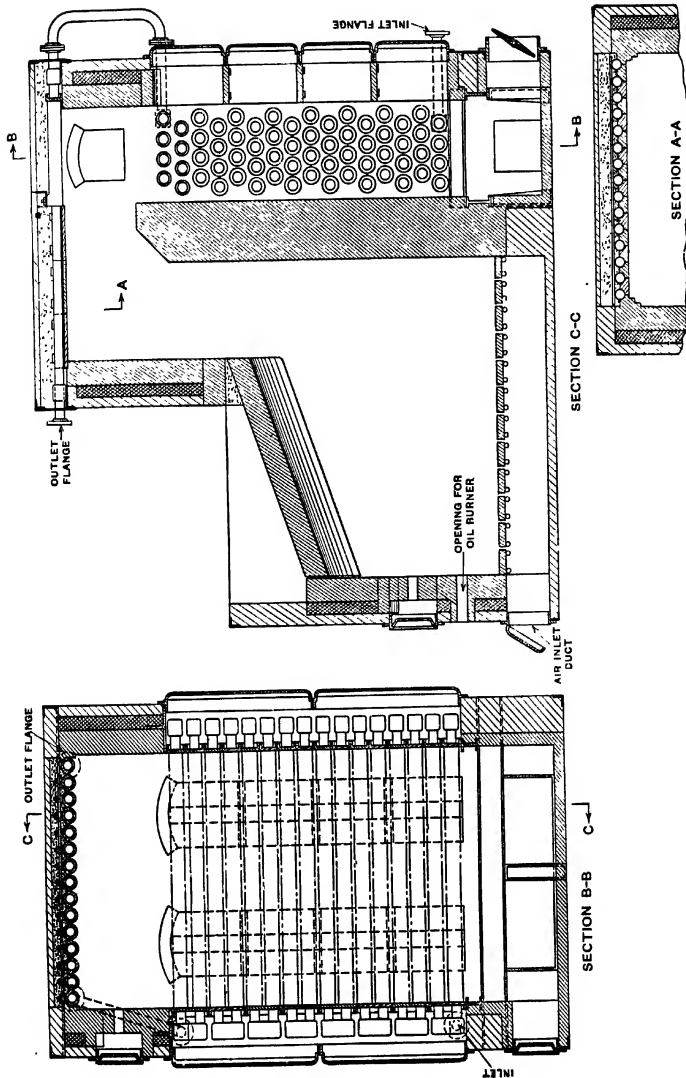


FIG. 35  
"Foster" tube still.

spherical heads on the still, although no conclusive reason can be advanced for this expensive construction. Fig. 36 shows in detail the plate arrangement of a modern steam still. The seams run directly around the still, resulting in less expensive construction than is common for a fire still.

Distillation is effected entirely by steam. Closed coils are placed in the bottom of the still, along with open steam sprays. Batch or continuous operation in batteries is possible. Single

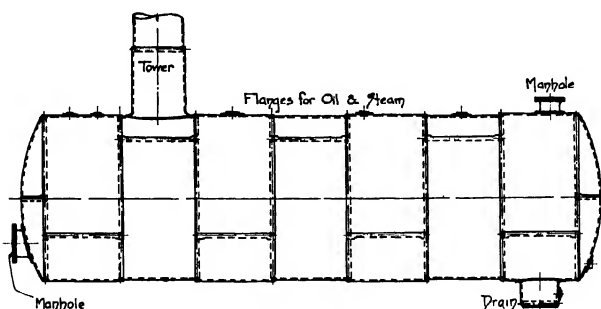


FIG. 36

Plate arrangement for steam stills.

stills may be run continuously. Fig. 37 illustrates a steam still thus arranged for continuous running. The shell is divided into four compartments by cross baffles. Small openings are left at the bottom to allow condensed water to flow to the water pot at the rear. The closed coils total 62.5 square feet of heating surface per 100 gallons taken overhead per hour; divided as follows: 33 per cent. in the first, 28 per cent. in the second, 22 per cent. in the third and 17 per cent. in the rear compartment. Such stills are usually equipped with a combined scrubbing and dephlegmating tower, as shown. The feed enters the top of this tower (after possibly passing through residual and vapor heat exchangers), and trickles down over the broken stone or tile contained in the tower. Here it meets the ascending vapors and steam, condensing and carrying back to the still the heavier fractions thereof.

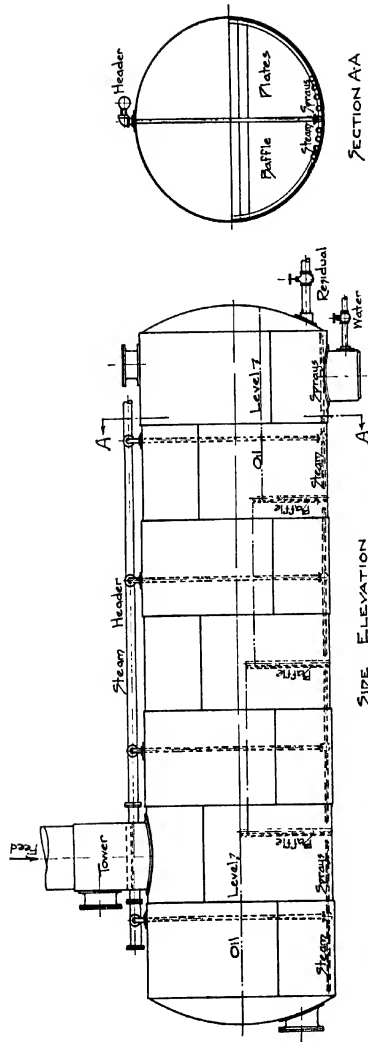


FIG. 37

Steam still arranged for continuous running.

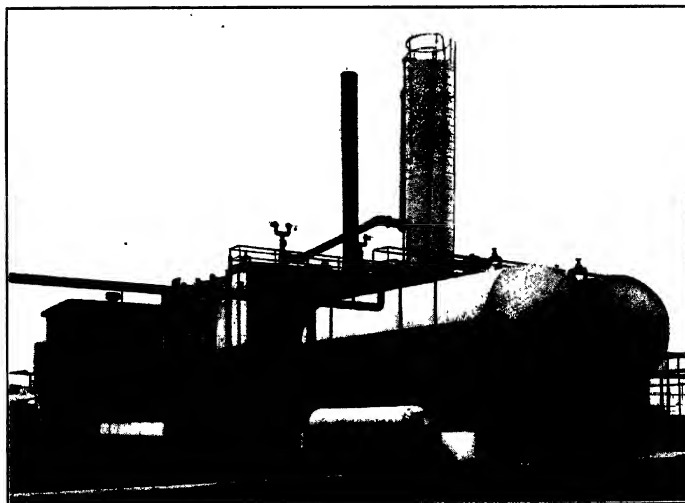


FIG. 38

Steam stills showing tower and condenser boxes.

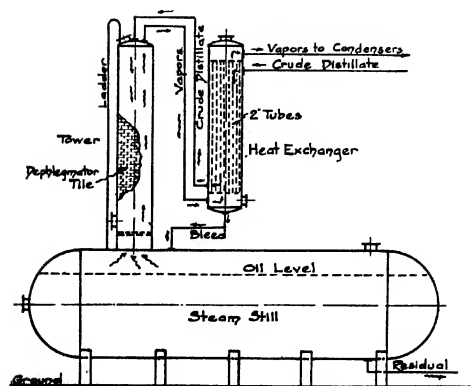


FIG. 39

Steam still with scrubbing tower and vapor heat exchanger.

A third method of running steam stills is the so-called "semi-continuous." No baffles are needed. The still is partly charged and heated, and distillation started. More stock is fed in continuously to make up for the portion distilled off, until the accumulated "bottom" or residual in the still has reached proportions to justify shutting down and pumping out. This method affords opportunity to utilize a vapor heat exchanger and a scrubbing tower, if desired, with consequent economy.

Steam still settings are very simple. Brick cross piers or structural steel frames are often used alone. To carry the tower and vapor heat exchangers, dividing walls of brick or concrete are sometimes used between stills. Fig. 39 shows a 10 × 30 foot steam still with tower, vapor heat exchangers and piping.

Vacuum stills may follow the general plate arrangement of the fire stills previously discussed. They are, however, usually smaller in diameter and longer for a given capacity than the fire stills. Heavy bracing is necessary to avoid collapse, under the high bottom temperatures. Double angle irons curved to the shell and riveted inside at about 5 foot centers are sufficient for the American wet vacuum system, for stills up to ten feet in diameter. To allow drainage and permit the open sprays to lie along the bottom, a construction of braces similar to that shown in Fig. 40 is recommended. In using the dry vacuum system with its possible high vacuums, the bracing should receive further attention. The heads are often made flat to enable I-beam stiffeners to be riveted on.

The fuel consumption necessary to distill oils is difficult of determination on account of variations in the latent and specific heats at various stages of the process. The most careful determination for one oil or stock cannot be used for another. In running to coke, estimates of 2,500 to 3,000 B.t.u. per gallon have been advanced. Part of the variation is no doubt due to differences in gravity. A chart may be constructed with the following assumed factors, if the distillation test is available:

Specific heat .....	0.5
Latent heat, gasoline .....	180 B.t.u.

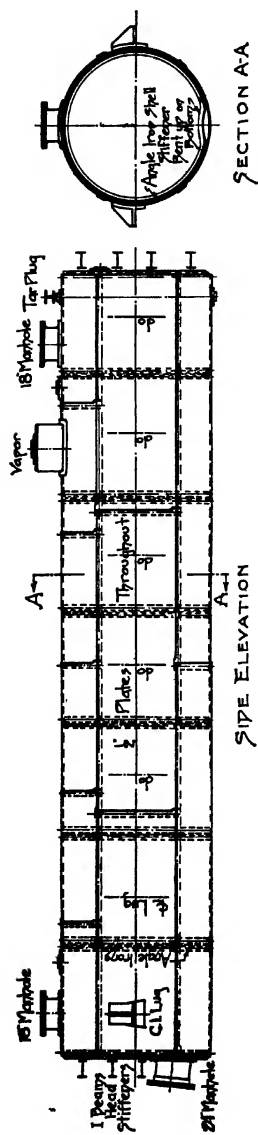


FIG. 40

Plate arrangement and bracing, vacuum still.

Latent heat, naphtha .....	125 B.t.u.
Latent heat, kerosene .....	120 B.t.u.
Latent heat, gas oil .....	115 B.t.u.
Latent heat, wax distillate .....	110 B.t.u.

Such a chart is shown in Fig. 41 for a crude oil of 37° Baumé. While based on values subject to variation, it nevertheless shows roughly the relation between the heat units required for distillation and the percentage of oil distilled from the original charge.

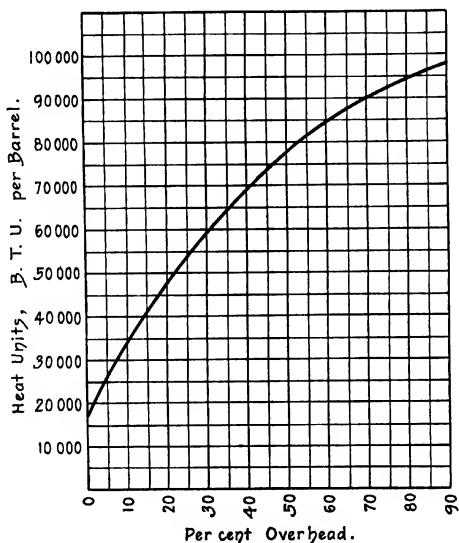


FIG. 41

Heat required for distillation of a barrel of typical Midcontinent crude oil.

The efficiency of the average oil still setting is notoriously poor. Several reasons contribute to this, the most important being the high temperature of the escaping flue gases. Compared with average boiler practice, these temperatures are very high; and must necessarily be so, since the temperature of the oil in the stills is also high, ranging from 500° to 700° F. at the end of a run. Better baffling and better attention to the amount of excess air will help to some extent; but without some sup-



plementary method of reclaiming the heat in the spent flue gases, it is impossible to reduce this heat loss below 25 to 30 per cent. of the heat evolved in the furnace.

In the case of continuous stills, vapor and residual heat exchange, as discussed in a later chapter, improves the efficiency.

There is some difference of opinion as to the advantage of mechanical stokers. Some refiners, after tests, claim that there is little saving on batch stills, on account of the different rates of firing during the run. Others favor the stokers. There can be little question of their efficiency under batteries of continuous stills, where each still is running with a practically constant coal consumption. The labor saving is also a strong argument for the stokers, but this has no bearing on fuel efficiency.

Tube stills, on account of the counterflow between oil and flue gases, show a much higher efficiency. The flue gases in this type of apparatus may be reduced in temperature to within 150° or 200° F. above the entering oil temperature.

Various methods may be adopted to reclaim the waste heat in flue gases and thus to improve the overall still battery efficiency. Waste heat boilers, feed water economizers, waste heat steam superheaters, oil preheaters and preheaters for air fed to the combustion chamber, have all been used. Feed water economizers set in the flues are very successful and give little trouble. The possibilities of this feature will be discussed in connection with the topic of refinery power houses. It should be noted that economizers will not raise the still battery efficiency, but that the resulting savings will appear in the power costs and hence in the overall plant efficiency.

Oil or air preheaters, however, will affect the efficiency of the battery itself. The usual type of oil preheater is a tube still of ordinary design, discharging into the first of a series of continuous stills instead of to the usual separator. Such a preheater cannot be recommended for batch stills.

Waste heat boilers are rarely used on new installations, since the modern tendency is to concentrate the steam generation in a central plant.

Oil firing permits of more efficient combustion than is possible when using coal. The amount of excess air can be materially reduced.

A tabulation of some results from actual practice follows:

TABLE 33: FUEL CONSUMPTION. OIL STILLS

* Oil	Per Cent. Over	Lbs. Coal per Bbl.	B.T.U. per Lb. of Coal	Per Cent. Oil	Remarks
Crude...	75	19	14,500	—	Continuous stills with elaborate vapor and residual exchangers.
Crude and Stocks	various	{ 24 average }	14,000	—	Part batch, part continuous.
Crude and Stocks	various	{ 26 average }	11,500	—	All batch, stokers under stills.
Crude...	85	—	—	4.0	Continuous: vapor heat exchanger.
Crude...	24	—	—	1.1	Continuous: topping.
Crude...	21.5	—	—	.88	Trumble stills.
Crude...	18.4	—	—	1.1	Trumble stills.
Crude...	24	—	—	1.6	Ordinary tube still.
Crude... (to coke)	36	14,000	—	—	Hand fired batch.
Stock....	65	29	14,000	—	Batch.
Stock....	97	35	14,000	—	Batch.

The striking fact in the above table is the variation in the reported fuel consumptions. Different oils and different types of apparatus account for the impossibility of constructive deductions.

The tests made by the Bureau of Mines and the Sinclair Refining Company, while confined to one general style of setting, allow conclusions to be drawn as to the effects of different conditions of firing and minor changes.

Table 34, condensed from records of these tests, will be of interest.

These tests show conclusively what can be done when attention is given to the question of fuel consumption. The fuels used were coal of 10,000 and oil of 19,000 B.t.u. heat content respectively.

For convenience in determining the fuel consumption of oil stills for various combined still and setting efficiencies, the chart of Fig. 42 is offered.

**TABLE 34**  
**STILL EFFICIENCIES AS AFFECTED BY FIRING METHODS**

Kind of Still	Method of Firing	Kind of Oil Distilled	Per Cent. of Oil Distilled Overhead	Fuel, Pounds per Barrel of Oil Chgd.	Efficiency of Still and Setting, Per Cent.	Flue Gas Temperature	Remarks
Batch...	{ chain grate stokers }	Crude	40	22.0	40.3	815	{ Single pass regular setting
Batch...		Wax dist.	87½	30.0	36.2	870	do.
Coking		Crude	to coke	41.4	28.8	945	do.
Batch...	do.	do.	42	17.2	51.6	725	{ Precaution to reduce excess air and cross baffles to make gases sweep the still bottom
Batch...	do.	Wax dist.	92.5	26.3	47.5	774	do.
Coking	do.	Crude	to coke	31.4	42.0	965	do.
Coking	oil	do.	do.	13.9	52.4	749	—
Batch...	{ Under-feed stoker }	Wax dist.	?	24.3	48.2	845	—
Batch...	do.	do.	?	19.0	61.2	390	{ Air for combustion pre-heated

The following efficiencies are recommended for use with the chart:

	Per cent.
Best type, oil-fired tube still .....	65
Ordinary oil-fired tube still .....	55-60
Continuous oil-fired cylindrical stills with vapor and residual exchangers .....	50
Ordinary oil-fired continuous stills .....	40
Batch stills, oil-fired .....	30
Coal-fired continuous stills with vapor and residual exchangers .....	45
Ordinary coal-fired continuous stills .....	35
Coal-fired batch stills .....	25

The above values make no allowance for apparatus to reduce the heat of the flue gases, which still further improve the efficiency in each individual case. Such improved efficiency may be a direct credit to the still battery, but is more likely to appear

Oil firing permits of more efficient combustion than is possible when using coal. The amount of excess air can be materially reduced.

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For convenience in determining the fuel consumption of oil stills for various combined still and setting efficiencies, the chart of Fig. 42 is offered.

TABLE 35: OIL STILL INSULATION SPECIFICATION

Still Operating Tempera- ture, Degrees F.	SPECIFICATION "A"	Section
250 to 300	<p>1½" Fine Corrugated Asbestocel sheets 36" x 36" for flat surfaces, blocks 6" x 36" for curved surfaces:—rough coat #302 cement, filling all joints in insulation:—Hex. netting scratch coat #302 cement:—finish coat #302 and Portland cements mixed and trowelled smooth.</p> <p style="text-align: center;">Heat Transmission</p> <p>Insulation Efficiency.    B.t.u./φ°diff./hr.</p> <p>250° — 89.83%            250° — .271</p> <p>300° — 90.51%            300° — .280</p>	
300 to 400	<p>2" Asbestos Sponge Felted sheets 24" x 36". Note:—(Sponge Felted is flexible and will lay snug on curved surfaces):—rough coat #302 cement filling all joints in insulation:—Hex. netting:—scratch coat #302 cement:—finish coat #302 and Portland cements mixed and trowelled smooth.</p> <p style="text-align: center;">Heat Transmission</p> <p>Insulation Efficiency.    B.t.u./φ°diff./hr.</p> <p>300° — 93.52%            300° — .191</p> <p>400° — 94.48%            400° — .200</p>	
400 to 500	<p>2½" Asbestos Sponge Felted sheets 24 x 36". Note:—(Sponge Felted is flexible and will lay snug on curved surfaces.):—rough coat #302 cement filling all joints in insulation:—Hex. netting:—scratch coat #302 cement:—finish coat #302 and Portland cements mixed and trowelled smooth.</p> <p style="text-align: center;">Heat Transmission</p> <p>Insulation Efficiency.    B.t.u./φ°diff./hr.</p> <p>400° — 95.42%            500° — .174</p> <p>500° — 96.13%            400° — .166</p>	
500 to 600	<p>1" Fire Felt sheets 24" x 36" curved to still radius:—2" Asbestos Sponge Felted sheets 24" x 36". Note:—(Sponge Felted is flexible and will lay snug on curved surfaces.):—rough coat #302 cement filling all joints in insulation:—Hex. netting:—scratch coat #302 cement:—finish coat #302 and Portland cements mixed and trowelled smooth.</p> <p style="text-align: center;">Heat Transmission</p> <p>Insulation Efficiency.    B.t.u./φ°diff./hr.</p> <p>500° — 96.11%            500° — .175</p> <p>600° — 96.60%            600° — .183</p>	

TABLE 35 (Cont.)

Still Operating Tempera- ture, Degrees F.	SPECIFICATION "A"	
600 to 750	<p>1" Fire Felt sheets 24" x 36" curved to still radius:—2½" Asbesto Sponge Felted sheets 24" x 36". Note:—(Sponge Felted is flexible and will lay snug on curved surfaces.):—rough coat #302 cement filling all joints in insulation:—Hex. netting:—scratch coat #302 cement:—finish coat #302 and Portland cements mixed and trowelled smooth.</p> <p>Insulation Efficiency.      Heat Transmission 600° — 97%+      B.t.u./φ°/diff./hr. 750° — 97%+      600° — .154 750° — 97%+      750° — .164</p>	
750 to 1,000	<p>1½" Fire Felt sheets 24" x 36" curved to still radius:—1-layer 1" Asbesto Sponge Felted sheets 24" x 36":—1-layer 1½" Asbesto Sponge Felted sheets 24" x 36". Note:—(Sponge Felted is flexible and will lay snug on curved surfaces.):—rough coat #302 cement filling all joints in insulation:—Hex. netting:—scratch coat #302 cement:—finish coat #302 and Portland cements mixed and trowelled smooth.</p> <p>Insulation Efficiency.      Heat Transmission 750° — 97%+      B.t.u./φ°/diff./hr. 1,000° — 97%+      750° — .153 1,000° — 97%+      1,000° — .170</p>	

for an installation using open steam exclusively. For reference in estimating the steam consumption of steam still installations, the following table is offered:

TABLE 36  
STEAM. LBS. PER GALLON OF OVERHEAD DISTILLATE  
GAUGE PRESSURES, 100 TO 150 LB.

	Degrees of Superheat, F.		
	0°	100°	200°
Batch running . . . . .	6.0	5.7	5.5
Continuous: no vapor heat exchange . . . . .	4.0	3.8	3.7
Continuous with vapor heat exchange . . . . .	2.4	2.2	2.1

These figures will suffice for present day grades of gasoline. When running "batch," however, the amount at the start will

not exceed perhaps 3 lb., gradually increasing to 9 or 10 lb. per gallon, with the average as above.

It seems hardly necessary to touch upon the necessity of proper still insulation if efficiency is to be attained, yet many refineries are run with scant attention to this important point. Take the case of a 1,000 barrel batch still with top and sides uncovered; the radiation from the still would represent nearly 4 tons of 12,000 B.t.u. coal per day, at ordinary oil still efficiencies. This loss is over half of the fuel required to feed the still, in ordinary work.

Many materials have been used for insulation. Originally, common brick were laid over the top; and later, hollow tile. The many joints and lack of flexibility, together with a mediocre insulating effect, condemn this method. The ideal insulation must resist the temperatures at which the still in question operates, must present a minimum of joints, must have high insulating efficiency and must resist weather conditions. Many products have been tried; such as magnesia, both block and plastic; blocks of infusorial earth; and various asbestos products. The specifications of the H. W. Johns-Manville Co. are reproduced in Table 35, to illustrate modern practice with one particular class of the above products.

## CHAPTER VIII

### CONDENSERS

Theoretical Considerations—Commercial Applications—  
Fractionating Condensers—Receiving Houses

The condensing problem of the refinery engineer includes many vexing uncertainties. In power practice, the physical constants of the steam are closely known. With oil vapors, there are encountered not only a variable latent heat, but numerous different conditions of operation. Consequently, refinery condenser practice is largely empirical, based on experience. The inefficiency of such practice is gradually being realized and some constructive effort has been applied.

As far as the physical constants are concerned, very little information is available in the literature. The amount of heat to be abstracted in condensation is determined by the following operations:

- Cool the vapors;
- Condense the vapors;
- Cool the distillate to a reasonable temperature.

Since the vapors are rarely superheated when they enter the condenser, the first item need receive attention only in rare instances.

The second operation is the most variable. Its value depends on the latent heat. Values for latent heat are discussed in Chapter IV.

The third operation is more accurately determinable, and the amount of heat depends only on the drop in temperature desired, and the specific heat; which latter may, for all practical purposes, be taken at 0.5.

Condensing problems are further complicated from the fact that most refiners use open steam sprays in the stills. The exceptions are those plants which practice skimming only, in



straight fire stills; where the quality of residual is neglected and the resulting cracking is even encouraged to increase the yield of light products. This exceptional case being the simplest, it will be discussed first.

The average latent heats of the usual cuts may be taken for calculation as follows:

	B.T.U. per lb.
Gasoline .....	130
Naphtha .....	125
Kerosene .....	120
Gas Oil .....	115
Wax distillate or fuel oil .....	110

The average temperatures of the distillates from straight fire distillation are easily determined by test, and are fairly well established in practice about as follows:

	°F.
Gasoline .....	280
Naphtha .....	325
Kerosene .....	450
Gas oil .....	540
Wax distillate or fuel oil .....	650

To determine the amount of heat to be removed, the following condenser outlet temperatures for the distillate may be regarded as typical:

	°F.
Gasoline .....	80
Naphtha .....	80
Kerosene .....	100
Gas Oil .....	120
Fuel oil .....	150

The calculations for heat to be absorbed per pound follow:

	B.T.U.
Gasoline .....	$130 + 0.5 (280-80) = 230$
Naphtha .....	$125 + 0.5 (325-80) = 248$
Kerosene .....	$120 + 0.5 (450-100) = 295$
Gas Oil .....	$115 + 0.5 (540-120) = 325$
Fuel Oil .....	$110 + 0.5 (650-150) = 360$

To apply these figures on the basis of B.t.u. per gallon, will require some consideration of the crude which is being distilled. For most practical purposes, the above values may be reduced as follows:

	B.t.u. per Gallon
Gasoline .....	1,420
Naphtha .....	1,605
Kerosene .....	2,100
Gas Oil .....	2,385
Fuel Oil .....	2,590

The use of these figures will be discussed later.

As above stated, the introduction of steam directly into the oil in the still changes conditions materially. First, the vapor temperatures are lowered; and second, the steam itself must either be trapped out or condensed. Very little work has been recorded on trapping the steam; and, in fact, it is difficult to devise a trap adapted to all needs. It is usual to assume that the steam will need to be condensed, and to arrange cooling surface and water supply accordingly.

The quantity of steam used varies greatly in different plants. What follows may be taken as representing the author's judgment as to the amount required, on the basis of considerable data from actual cases.

When distilling a crude oil in a fire still with the aid of bottom steam, the gasoline and naphtha may be taken over practically dry; since the temperatures attained will not be sufficiently high to decompose or crack the valuable residuals. Most refiners nevertheless allow some steam to enter the still from the start. More steam is introduced as the kerosene and gas oil stocks come over, and when the final wax distillate cut is taken, the steam supply is at a maximum. The total amount of steam ranges from one-quarter to one-half the total amount of distillates, by volume of liquid measurement. The distribution of this steam through the various cuts is about as follows:

Gasoline } .....	1 lb. per gallon
Naphtha } .....	
Kerosene stock .....	4 lbs. per gallon
Gas oil .....	5 lbs. per gallon
Wax distillate .....	10-12 lbs. per gallon

These figures will vary with the ideas of the still man and it is probable that the quantity is often increased. This is particularly true of the wax distillate cut, when the still may be given "all the steam it will take." Records show that, at times, the volume of water coming from the condensers may be 7 to 9 times the volume of distillate at the end of the wax distillate cut. To be on the side of safety, in condenser calculations, it is therefore advisable to increase the allowances for steam to the following amounts:

	lb. per Gall.
Gasoline .....	1
Naphtha .....	1
Kerosene .....	5
Gas Oil .....	8
Wax distillate .....	24

Another special factor to be considered in connection with the use of open steam is the reduction of vapor temperatures, due to the law of partial pressures. This reduction will, of course, vary with the nature of the distillates and with the proportion of steam used. For ordinary calculations, the average temperatures of the mingled oil vapors and steam leaving the still may be taken as follows:

	°F.
Gasoline .....	250
Naphtha .....	295
Kerosene distillate .....	415
Gas Oil .....	490
Wax distillate .....	590

The steam, at atmospheric pressure, is obviously superheated, especially during the latter part of the run. The distillate outlet temperatures may be assumed as before. The amounts of heat to be abstracted from the oils may now be calculated:

	B.t.u. per Lb.
Gasoline .....	$130 + 0.5 (250-80) = 215$
Naphtha .....	$125 + 0.5 (295-80) = 233$
Kerosene .....	$120 + 0.5 (415-100) = 278$
Gas Oil .....	$115 + 0.5 (490-120) = 300$
Wax distillate .....	$110 + 0.5 (590-150) = 330$

At the average gravities of these cuts, the heats per gallon are as follows:

	B.t.u.
Gasoline .....	1,330
Naphtha .....	1,510
Kerosene .....	1,890
Gas Oil .....	2,085
Wax distillate .....	2,360

To these figures must be added the heats abstracted from the steam, as follows:

	Lib	B t u. per Lib.	Total B.t.u. per Gall. Distillate
Gasoline .....	1	1,120 =	1,120
Naphtha .....	1	1,141 =	1,141
Kerosene .....	5	1,177 =	5,885
Gas Oil .....	8	1,215 =	9,720
Wax distillate .....	24	1,209 =	29,016

The above tabulations show in detail the important effect on condenser design of the use of steam in the still. The total heat abstraction for each gallon of the oil distillates is the sum of the last two values, as follows:

	B.t.u. per Gall.
Gasoline .....	2,450
Naphtha .....	2,651
Kerosene .....	7,775
Gas Oil .....	11,805
Wax distillate .....	31,376

The total quantity of distillate may be greatly augmented by the condensed water. Since the quantity usually known is the amount of oil distilled in a given time, the figures as above given will prove convenient for ordinary use.

With water as a condensing agent, we have four variable factors to consider; the amount of water, the temperatures of the water, in and out; and the amount of surface provided for the exchange of heat. A change in one of these factors affects one or more of the others. For ordinary purposes, it is not advisable to attempt to cool the distillates nearer than within 10° of the inlet temperature of the water. Preferably, this

limit should be 20°. For instance, to reduce gasoline and naphtha distillates to the temperature of 80°, as previously recommended, 60° cooling water is desirable but 70° water can be used if positively necessary.

Heat transfer is almost directly proportional to the difference in temperature of the two substances involved. The mean difference in temperature cannot, however, be taken as the difference between the average of the inlet and the outlet temperatures of the two mediums, except for the most elementary calculations. Figure 43, representing the conditions of parallel flow and counter-flow, shows this fact graphically. The mean temperature difference is expressed by the formula:

$$d = \frac{T - t}{\log_e \frac{T}{t}}$$

$d$  = mean temperature difference;  
 $T$  = maximum original difference;  
 $t$  = minimum final difference.

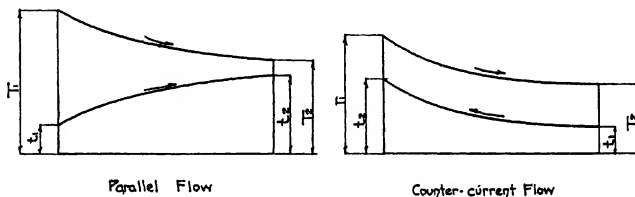
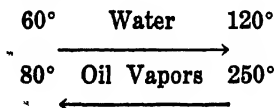


FIG. 43

Diagram of heat exchange.

As an example, let it be assumed that the oil vapors enter and leave the condenser at 250° and 80° F., respectively. Cooling water enters at 60° and leaves at 120° F. Graphically this may be shown as follows:



The original difference is 130° and final 20°. Substituting 130° for  $T$  and 20° for  $t$  in the formula, the mean difference is:

$$d = \frac{130 - 20}{\log_e \frac{130}{20}} = 58.8^\circ \text{ F.}$$

The transmission of heat is expressed in terms of a constant,  $\rho$ , representing the number of B.t.u. transferred per hour per 1° difference in mean temperature between the two substances, per square foot of transmitting surface. This constant has a value which is dependent upon the velocity and nature of the two substances.

The various types of condensing apparatus in general use may be grouped as follows:

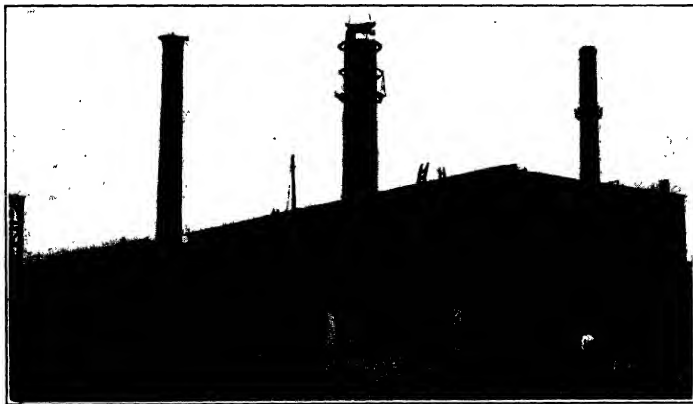
Submerged coil,  
Shell and tube,  
Jet.

Eliminating the last named, to be later discussed, the heat transfer conditions of the first two will now be taken up.

The submerged coil type is the outcome of the original spiral worms of the early stills. The reader is referred to the latter part of this chapter for drawings and photographs. The water velocity is extremely low, and the vapor velocities are much below those in other types of apparatus. By using headers and small pipes, somewhat better results are attained. In both cases, counter-flow can scarcely be approximated. Tests available on continuous coils show values of  $\rho$  of only 6 to 8 B.t.u. per 1° arithmetic mean temperature difference. (Unfortunately, details of the tests are not available from which to compute the true mean temperature.) For the conditions encountered, the arithmetic mean temperature was probably about 5/4 of the true mean temperature difference, so that the probable true value of  $\rho$  was 7.5 to 10 B.t.u. With parallel coils of relatively small diameter, 25 per cent. better transfer rates are reported.

Modifications of the standard cast or wrought iron pipe coils

are various shapes designed to give a large amount of surface per lineal foot, with relatively high velocities. Radiator sections, such as cast iron barrel with ribs or flanges at right angles



*(Courtesy Chicago Bridge and Iron Works)*

FIG. 44

Condenser boxes, Midwest Refining Company, Casper, Wyoming.

thereto, have been tried. The Vento sections of the American Radiator Company are examples of this class. Rates of transfer from 25 per cent. to 10 per cent. higher than the figures attainable in the best coil practice are suggested by this company.

With shell and tube condensers, designed for velocities of 2 to 3 feet per second, transfer rates of from 18 to 50 B.t.u. have been reported. These figures are for transfer from water to oil vapors.

The transfer rate from water to steam is much higher. This is especially true in the case of the shell and tube type condenser, where high water velocities may be attained and where a value of  $\rho$  of 300 to 400 B.t.u. is often attained in practice. For the submerged coil types, these values are undoubtedly too high, on account of the low water velocities encountered.

From the above discussion, rates of transfer are recommended as follows:

TABLE 37

To	Submerged Continuous Coil	Submerged Parallel Coil	Shell and Tube
Oil vapors .....	6	7.5	35
Steam .....	50	62.5	250

For the various mixtures of oil and steam previously discussed, the heat transfer may be calculated on the assumption that the actual rate is in direct proportion to the relative amounts at the previously given rates for each. On this assumption, values of  $\rho$  for the various conditions encountered are as follows:

TABLE 38

	Continuous Submerged Coils	Parallel Submerged Coils	Shell and Tube
Gasoline and naphtha, 1 lb. steam per gallon	12	15	65
Kerosene, 5 lbs. steam per gallon .....	25	31	126
Gas oil, 8 lbs. steam per gallon .....	29	36	149
Fuel oil or lubricants, 24 lbs. steam per gallon .....	40	50	200
All "dry" distillates .....	6	7.5	35

To facilitate the design of condensers, the following tables are offered, based upon the preceding discussion, with an allowance of 10 per cent. in the surface to cover unforeseen conditions such as scale or wax deposits on the exterior or interior of the tubes respectively. In fact, if the condensing water is known to be very hard, an additional 10 per cent. allowance is advisable. Column I is for continuous submerged coils. Column II for submerged coils with multiple smaller pipes (parallel type), and Column III is for shell and tube apparatus with water velocities exceeding two feet per second. Water outlet temperatures of over 150° F. are not recommended for Column III. on account of the possibility of scale deposits:



TABLE 39  
CONDENSER SURFACE AND COOLING WATER REQUIREMENTS  
*Gasoline: No Steam*

B.t.u. to be removed per gallon = 1,420. Vapor: In at 280°. Out at 80°.

Water Inlet °F.	Water Outlet °F.	Mean Temperature Difference °F.	Square Feet of Transmitting Surface per Gallon of Distillate per Hour			Gallons of Water per Gallon of Distillate
			I	II	III	
60	100	73	3.58	2.86	.61	4.26
	120	67	3.90	3.12	.67	2.84
	140	61	4.30	3.44	.74	2.14
70	100	59	4.41	3.53	.76	5.70
	120	54	4.83	3.86	.83	3.41
	140	49	5.32	4.25	.91	2.42

*Naphtha: No Steam*

B.t.u. to be removed per gallon = 1,605. Vapor: In at 325°. Out at 80°.

Water Inlet °F.	Water Outlet °F.	Mean Temperature Difference °F.	Square Feet of Transmitting Surface per Gallon of Distillate per Hour			Gallons of Water per Gallon of Distillate
			I	II	III	
60	100	85	3.40	2.76	.58	4.82
	120	79	3.72	2.97	.64	3.21
	140	74	3.96	3.16	.68	2.40
70	100	69	4.16	3.33	.71	6.42
	120	65	4.51	3.51	.77	3.85
	140	60	4.90	3.92	.84	2.75

*Kerosene Distillate: No Steam*

B.t.u. to be removed per gallon = 2,100. Vapor: In at 450°. Out at 100°.

Water Inlet °F.	Water Outlet °F.	Mean Temperature Difference °F.	Square Feet of Transmitting Surface per Gallon of Distillate per Hour			Gallons of Water per Gallon of Distillate
			I	II	III	
60	120	137	2.80	2.24	.48	4.20
	140	131	2.94	2.35	.50	3.16
	160	126	3.05	2.44	—	2.52
70	120	125	3.08	2.46	.53	5.04
	140	120	3.20	2.56	.55	3.60
	160	114	3.38	2.70	—	2.80
80	120	111	3.47	2.78	.59	6.30
	140	106	3.64	2.91	.62	4.20
	160	101	3.82	3.06	—	3.16

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TABLE 39 (Cont.)  
Gas Oil: No Steam

B.t.u. to be removed per gallon = 2,385. Vapor: In at 540°. Out at 120°

Water Inlet °F.	Water Outlet °F.	Mean Temperature Difference °F.	Square Feet of Transmitting Surface per Gallon of Distillate per Hour			Gallons of Water per Gallon of Distillate
			I	II	III	
60	150	177	2.47	1.97	—	3.18
	170	170	2.57	2.06	—	2.60
	190	164	2.66	2.13	—	2.20
70	150	166	2.64	2.11	—	3.58
	170	160	2.73	2.18	—	2.86
	190	154	2.84	2.27	—	2.38
80	150	154	2.84	2.27	—	4.10
	170	148	2.95	2.36	—	3.18
	190	143	3.06	2.44	—	2.60

Fuel Oil or Wax Distillate:  
No Steam

B.t.u. to be removed per gallon = 2,590. Vapor: In at 650°. Out at 150°.

Water Inlet °F.	Water Outlet °F.	Mean Temperature Difference °F.	Square Feet of Transmitting Surface per Gallon of Distillate per Hour			Gallons of Water per Gallon of Distillate
			I	II	III	
60	160	236	2.02	1.62	—	3.10
	180	230	2.06	1.65	—	2.58
	200	224	2.12	1.70	—	2.22
70	160	224	2.12	1.70	—	3.44
	180	220	2.16	1.74	—	2.82
	200	214	2.22	1.78	—	2.39
80	160	215	2.21	1.77	—	3.89
	180	210	2.26	1.81	—	3.10
	200	204	2.33	1.87	—	2.58

Gasoline—1 lb. Steam per Gallon

B.t.u. to be removed per gallon of dist. = 2,450. Vapor: In at 250°. Out at 80°.

Water Inlet °F.	Water Outlet °F.	Mean Temperature Difference °F.	Square Feet Surface per Gallon of Distillate per Hour			Gallons of Water per Gallon of Distillate
			I	II	III	
60	100	65	3.46	2.77	.64	6.12
	120	59	3.80	3.04	.70	4.08
	140	53	4.24	3.39	.78	3.06
70	100	52	4.31	3.45	.80	8.16
	120	47	4.80	3.84	.89	4.90
	140	44	5.10	4.08	.94	3.50

TABLE 39 (Cont.)  
*Naphtha—1 lb. Steam per Gallon*

B.t.u. to be removed per gallon of dist.=2,651. Vapor: In at 295°. Out at 80°.

Water Inlet °F.	Water Outlet °F.	Mean Temperature Difference °F.	Square Feet Surface per Gallon of Distillate per Hour			Gallons of Water per Gallon of Distillate
			I	II	III	
60	100	77	3.14	2.51	.58	6.61
	120	72	3.37	2.68	.62	4.42
	140	66	3.67	3.02	.68	3.31
70	100	62	3.90	3.12	.73	8.83
	120	58	4.18	3.34	.77	5.30
	140	53	4.56	3.65	.85	3.80

*Kerosene: 5 lb. Steam per Gallon*

B.t.u. to be removed per gallon = 7,775. Vapor: In at 415°. Out at 100°.

Water Inlet °F.	Water Outlet °F.	Mean Temperature Difference °F.	Square Feet Surface per Gallon of Distillate per Hour			Gallons of Water per Gallon of Distillate
			I	II	III	
60	120	127	2.66	2.12	.56	12.95
	140	122	2.79	2.23	.59	9.72
	160	116	2.95	2.35	—	7.77
70	120	116	2.95	2.35	.63	15.55
	140	111	3.08	2.46	.66	11.10
	160	105	4.25	2.63	—	8.63
80	120	102	4.34	2.68	.72	19.40
	140	98	3.48	2.78	.75	12.95
	160	92	3.71	2.97	—	9.72

*Gas Oil: 8 lb. Steam per Gallon*

B.t.u. to be removed per gallon = 11,805. Vapor: In at 590°. Out at 120°.

Water Inlet °F.	Water Outlet °F.	Mean Temperature Difference °F.	Square Feet of Surface per Gallon of Distillate per Hour			Gallons of Water per Gallon of Distillate
			I	II	III	
60	160	188	2.39	1.91	—	14.18
	180	182	2.46	1.97	—	11.80
	200	176	2.55	2.04	—	10.10
70	160	177	2.53	2.02	—	15.78
	180	172	2.61	2.09	—	12.88
	200	166	2.70	2.16	—	10.90
80	160	165	2.72	2.18	—	17.70
	180	159	2.82	2.25	—	14.18
	200	154	2.92	2.34	—	11.80

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TABLE 39 (Cont.)

*Wax Distillate: 24 lb. Steam per Gallon*

B.t.u. to be removed per gallon = 31,376. Vapor: In at 590°. Out at 150°.

Water Inlet °F.	Water Outlet °F.	Mean Temperature Difference °F.	Square Feet of Surface per Gallon of Distillate per Hour			Gallons of Water per Gallon of Distillate
			I	II	III	
60	150	221	3.90	3.12	.78	42
	170	214	4.02	3.21	—	34
	190	208	4.14	3.31	—	29
	210	201	4.28	3.42	—	25
70	150	212	4.06	3.24	.81	47
	170	205	4.20	3.36	—	38
	190	198	4.35	3.38	—	31
	210	192	4.48	3.49	—	27
80	150	201	4.28	3.42	.86	54
	170	195	4.42	3.53	—	42
	190	189	4.56	3.64	—	34
	210	184	4.69	3.75	—	29

Let it be assumed that the rates of evaporation from various sized stills are as follows, in gallons of distillate per hour:

Still	Running Batch	Continuous
8 x 24 .....	192	294
10 x 30 .....	300	460
12 x 36 .....	432	662
14 x 42 .....	588	902
15 x 45 .....	675	1,035

For an 8 × 24 foot still, the surface in square feet necessary for condensers will be as follows on the basis of 60° water, with maximum outlet temperatures as tabulated:

TABLE 40: CONDENSER SURFACES, 10' × 24' STILL

Stock		Continuous Coil		Parallel Coil		Shell and Tube	
		Batch	Cont.	Batch	Cont.	Batch	Cont.
Dry .....	Gasoline .....	825	1,260	660	1,010	141	216
	Naphtha .....	760	1,166	608	932	130	199
	Kerosene .....	585	895	468	716	100	153
	Gas Oil .....	510	780	408	625	88	135
	Fuel Oil .....	408	625	326	500	70	107
	Gasoline . *	815	1,250	652	998	184	282
With Steam	Naphtha .....	685	1,050	547	838	155	248
	Kerosene .....	566	868	452	691	90	138
	Gas Oil .....	490	750	392	600	76	116
	Wax Dist. ....	821	1,258	657	1,010	132	202

The above table should not be taken as necessarily indicating the actual surface to be installed, its purpose being rather to exhibit the influence of different conditions. An inspection of the table shows several interesting facts. First is the great efficiency of the shell and tube type of condenser over the submerged coil. The additional surface required for continuous running should be noted. Distillation with steam requires slightly less surface than dry distillation, until a point is reached where the quantity of steam reaches very large proportions. Thereafter, steam represents most of the heat content.

The practical considerations which influence the choice of type and surface of condensers should next be investigated. In the case of batch stills, the worst condition is that which occurs when the gasoline or first off is distilling dry. The condition is practically the same when running with steam; so that if condensers are designed to take care of the first cut, the surfaces will be ample for the rest of the run. In continuous dry distillation, the surfaces in use may be reduced materially after the first two cuts; and this may also be the case when using open steam if means are taken to trap out and remove the steam in the last stills, from which the "overhead" is the wax distillate cut.

Regarding types of apparatus, the continuous coil is the most popular and satisfactory for all conditions. The parallel coil is more efficient for heat transfer. In any system of pipes branching from a header, however, the slightest difference in surface conditions or bore will alter the velocities of the fluid as between neighboring pipes. In oil condenser work when handling heavy stocks, such as the wax distillate, this change in velocity is liable to cause trouble, since in the cooler portions of the coil wax may congeal and possibly plug the pipe. There is no way of knowing this fact, which would obviously be immediately discovered were continuous coils in use. For the same reason, the parallel coil is harder to clean when preparing for the next run, with the consequent possibility that the first distillates carried over may be badly off-color. For these reasons,

parallel coils cannot be recommended for batch crude stills. For a battery of continuous stills, they are better than continuous coils on the first stills until the kerosene cut is over. For the balance of the stills, the continuous coil is to be recommended. For stills re-running naphtha or kerosene distillates, the parallel coil is satisfactory and its use decreases the amount of surface necessary.

The shell and tube apparatus is open to the same objections as parallel coils. Its use is also limited to a water outlet temperature of 150° unless the quality of the water is above question.

Another question to consider in connection with a batch installation is whether the stills may not at some future date be arranged to run continuously. About the minimum quantity of crude to which continuous distillation is adapted is 1,500 barrels per day. In a small refinery which will never expand above such an amount, this question may be neglected. If first cost is vital, there is always the possibility, if the stills are later rearranged to run continuously, of increasing the amount of water; thus decreasing the water outlet temperature, and by building

TABLE 41  
CONDENSER SURFACES IN SQUARE FEET FOR VARIOUS SIZES OF  
STILLS AND VARIOUS KINDS OF SERVICE

		Batch Stills	Continuous Stills Dry Distillation				Continuous Stills With Steam			
		All Cuts	Gasoline Kerosene Naphtha			Bal- ance of Cuts	Gasoline Kerosene Naphtha			Bal- ance of Cuts
Type of Condenser . . . .		I	I	II	III	I	I	II	III	I
Stills	Capac- ity, Bbl.									
8' x 24' . . . .	180	825	1,260	1,010	216	900	1,250	998	282	850
10' x 30' . . . .	350	1,290	1,970	1,580	338	1,410	1,955	1,565	441	1,330
12' x 36' . . . .	615	1,850	2,840	2,280	487	2,030	2,810	2,250	635	1,915
14' x 42' . . . .	1,000	2,530	3,860	3,100	661	2,760	3,830	3,060	865	2,615
15' x 45' . . . .	1,200	2,900	4,440	3,560	760	3,170	4,400	3,520	1,000	3,000

I—Continuous Submerged Coils;

II—Parallel Submerged Coils;

III—Shell and Tube Condensers.

up a higher mean temperature difference, forcing the condensers to take the increased load. This is not economical; and for every installation, where possible, the condensers should be figured for the probable future contingency.

With these practical considerations in mind, as well as the preceding calculations, recommendations for various sizes of stills adapted to different service conditions follow. Table 41 is based on a mean annual water temperature of 60°. Where the mean annual water temperature is 70°, an increased allowance of surface of 10 to 12 per cent. is advisable. Summer temperatures will be above the average mean temperature, a condition which is met by using more water at that time.

The question of the amount of water is important. In the foregoing tables, there are shown the actual amounts required. The water necessary to condense the cuts from a barrel of oil may be approximated as follows:

TABLE 42: WATER AT 60° F. REQUIRED TO CONDENSE ONE BARREL OF CRUDE OIL. STEAM USED IN STILL

Cut	Per Cent.	Gallons of Distillate	Gallons of Water	Water Total
Gasoline.....	10	4.2	12.9	12.9
Naphtha.....	20	8.4	27.8	40.7
Kerosene distillate.....	15	6.3	49.0	89.7
Gas oil.....	12	5.0	50.5	140.2
Wax dist.....	20	8.4	210.0*	350.2

\* Note: Can be reduced one half if steam is properly trapped, making a total of 245 gallons instead of 350. A similar calculation shows 382 gallons of water at 70° to be required if the steam is not trapped, and 269 gallons if the steam is trapped. Dry distillation requires 74 gallons per barrel with water at 60° and 83 gallons at 70°, for an equal overhead.

The most convenient way to compute water requirements for the refinery condensers is to deduce from the flow sheet the amount of re-running to be done and to allow the tabulated quantities for each barrel of either crude or stocks charged to the stills. This method will, in itself, afford a suitable margin of safety, on account of the fact that only a portion of the re-running will be carried down as far as the crude distillation itself.

Submerged coils are placed in water boxes of various designs. For a battery of stills, one box divided into compartments by bulkheads is the usual practice. Stiffening members and tie

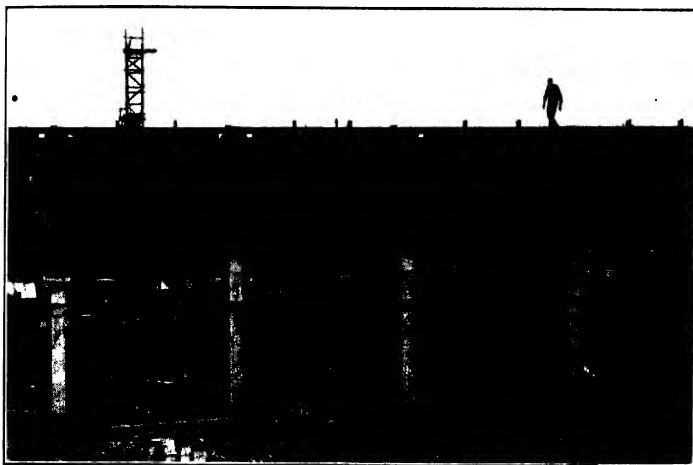


FIG. 45

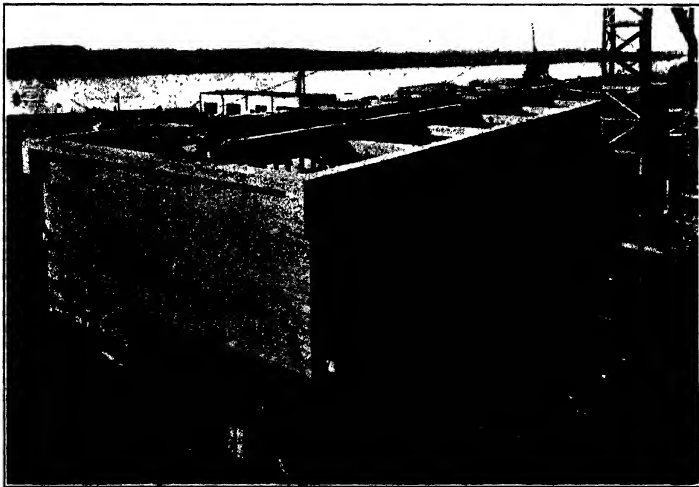
Condenser box with outside stiffening members.

rods are provided, according to approved engineering standards. A steel box of the usual design is shown in Fig. 44. This box has the stiffening members placed inside. Some refiners prefer outside stiffeners, with tie rods eliminated except over the top of the box, as shown by Fig. 45, particularly if salt or brackish water is to be used. A box of particular interest is that shown in Fig. 46. This is made entirely of reinforced concrete. It was built at a period when steel was difficult to obtain on account of war conditions. Entire success is reported for this installation.

Condenser supports for the box are usually of concrete. Longitudinal walls under the bulkheads support steel I-beams or reinforced concrete beams, upon which the box rests. Fig. 47 represents this construction. Flat slab construction on columns as shown by Fig. 48 has also been used. While presenting a



neat appearance, the construction interferes with bottom inspection. The outlets of the coil should be sufficiently high to give a free fall through the condenser box to a receiving tank. The spaces between the piers of the first mentioned design may, at slight additional cost, be utilized for hose, toilet and change



*(Courtesy C. B. Roberts Eng. Co.)*

FIG. 46

Condenser boxes of re-inforced concrete. Fall River refinery of the New England Oil Co.

rooms, and for other purposes. This practice is common. It has been claimed that the clear space provided under condensers with the flat slab construction decreases the fire risk. It is difficult to see any real added risk especially as the stills are rarely in batteries of more than ten, thus leaving a considerable aisle for every ten stills.

In selecting pipe sizes, the question of avoiding a too rapid contraction of area, with the possibility of back pressure and hence a reduction of the distillation rate, is important. From observation of the action of stills, it is recommended that 0.15 square inch be provided at the inlet for each gallon of overhead distillate from the still per hour.

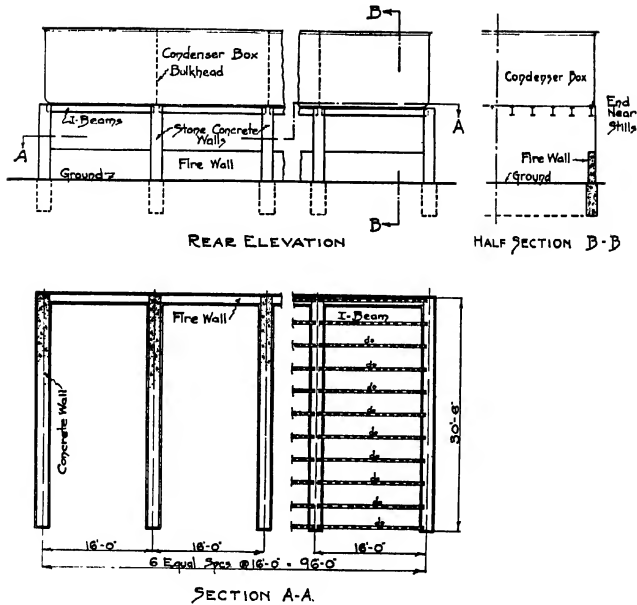


FIG. 47

Condenser box supports.

Cast iron pipe is to be preferred in all cases where first cost is not absolutely vital. The corrosion experienced when condensing petroleum vapors renders the life of steel pipe very uncertain. Cast iron coils will last for years. Experience has demonstrated the desirability of using pipe of extra thickness. The standards for oil refinery condensers adopted by the U. S. Cast Iron Pipe and Foundry Co. are given in the following table.

TABLE 43  
FLANGED PIPE FOR CONDENSER COILS

Nominal Diameter, Inches	Actual Outside Diameter, Inches	Thickness, Inches	Diameter of Flange, Inches	Thickness of Flange, Inches	Bolt Circle Diameter, Inches	Number of Bolts	Size of Bolts, Inches	Approximate Weight, Pounds per		
								Single Flange	Foot of Barrel	12-foot Length
4	5.26	0.63	9.00	$1\frac{1}{8}$	7.50	8	$\frac{1}{2}$	10.2	28.6	364
6	7.38	0.75	11.00	1	9.50	8	$\frac{3}{4}$	13.6	48.8	613
8	9.60	0.75	13.50	$1\frac{1}{8}$	11.75	8	$\frac{3}{4}$	20.7	65.1	823
10	11.84	0.75	16.00	$1\frac{3}{8}$	14.25	12	$\frac{1}{2}$	28.1	81.5	1,034
12	14.08	0.88	19.00	$1\frac{1}{2}$	17.00	12	$\frac{3}{4}$	41.5	113.8	1,449

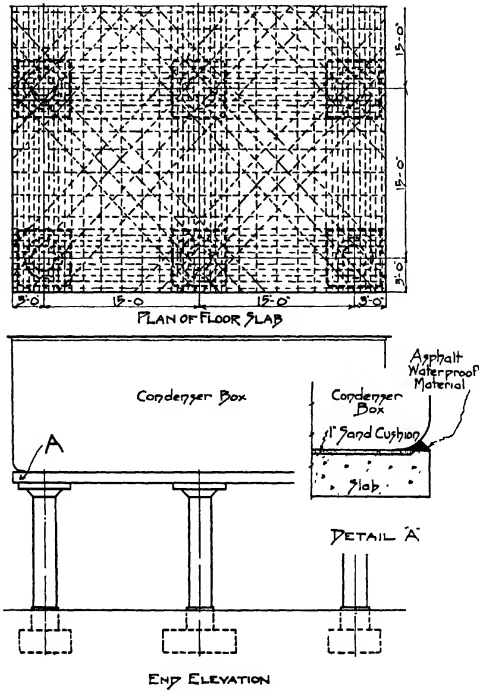


FIG. 48

Condenser box supports of "flat slab" type of reinforced concrete construction.

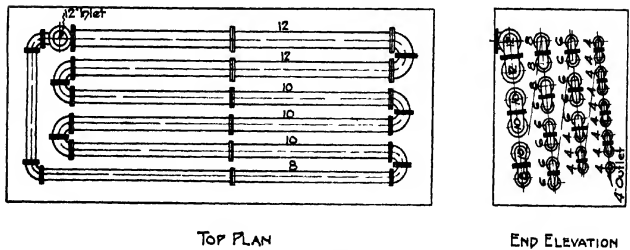


FIG. 49

Condenser coil, continuous type.

Coils made of the above pipe are usually assembled with asbestos ring gaskets  $\frac{1}{16}$  inch to  $\frac{1}{8}$  inch in thickness. Figs. 49 and 50 illustrate typical assemblies.

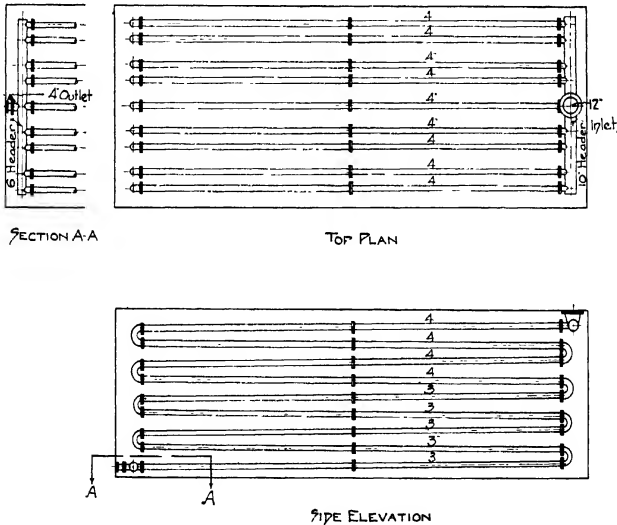


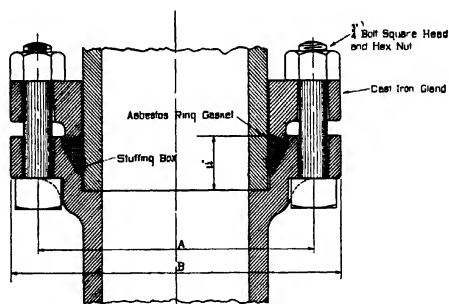
FIG. 50

Condenser coil. Parallel type with headers.

Another type of cast iron pipe, especially designed for condenser work, is that of the American Cast Iron Pipe Company. This pipe (termed "Simplex") is assembled with a stuffing box joint. The advantages claimed are, ease of assembly and the elimination of beveled flanges and similar methods for permitting deflection. Fig. 51 illustrates the "Simplex" joint.

The Vento sections of the American Radiator Company, previously referred to, are illustrated by Fig. 52. It is apparent that these sections lend themselves successfully to parallel coil construction; hence, they are especially useful in condensers for topping stills or for the light distillate stills of a continuous battery, rather than on batch stills running to cylinder stock or coke.

Many of the surface condensers designed for power house work have in recent years been adapted for the condensation of



Dimensions A and B are American  
Standard for 125 lbs pressure  
(See page 27)

STD. BOLTING FOR SIMPLEX FLGS.

Size Pipe	Bolt Circle	Number Bolt	Size Bolt	Length Bolt
3"	6"	4	1"	31"
4"	7 1/2"	4	1 1/2"	31"
6"	9 1/2"	4	2"	31"
8"	11 1/2"	8	2 1/2"	4"
10"	13 1/2"	8	3"	4"
12"	15 1/2"	8	3 1/2"	4"

FIG. 51

Detail of Simplex condenser pipe joint

petroleum vapors. Among these there may be mentioned the following makes:

Griscom-Russell, "Multiwhirl";  
Schütte & Koerting;  
Wheeler;  
Alberger Heater Company;  
Alberger Pump & Condenser Co.

The Griscom-Russell apparatus is illustrated by Fig. 53. The water (which, in this case, is outside of the tubes) is given a high velocity, counter-current and across the tubes, by the helical

baffles. The apparatus is single-pass. The Schütte & Koerting condenser is somewhat similar, except that the water is inside of the tubes and the vapors pass around them, guided by horizontal baffles ( Fig. 54). The Wheeler, and Alberger Pump &

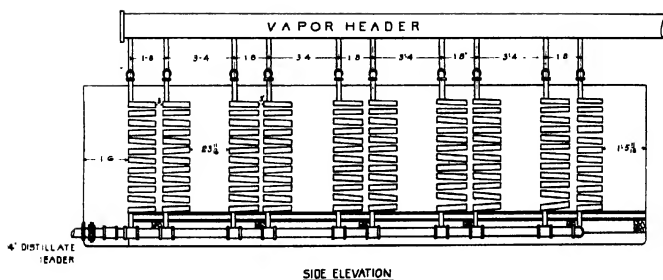
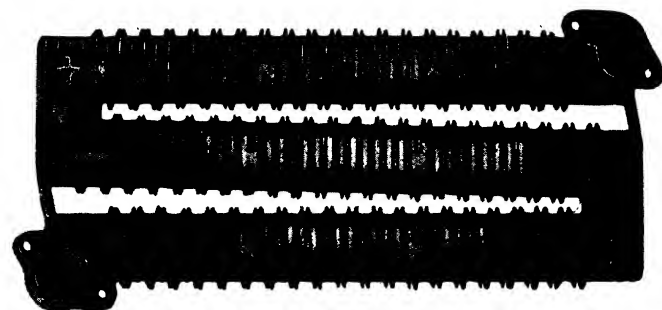


FIG. 52

"Vento" condenser section and assembly.

Condenser apparatus is of the multipass type, as distinguished from the single pass of the first two. An Alberger Pump & Condenser Company's condenser is shown in Fig. 55.

The Leman tubular condenser was designed primarily for the condensation of oil vapors. The vapors, flowing generally countercurrent to the water inside of the tubes, are also made

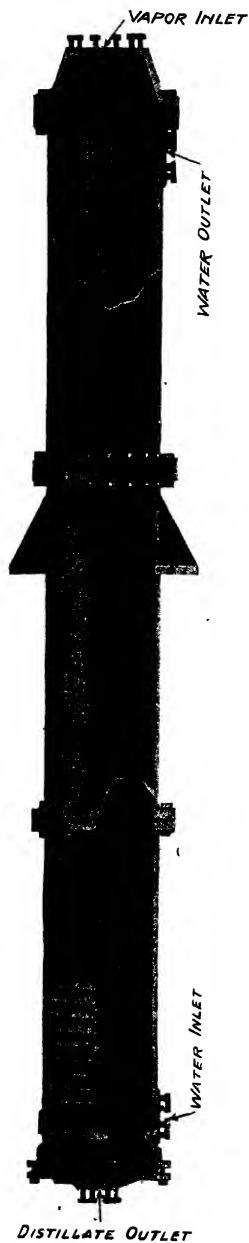


FIG. 53

Grisco-Russel "Mul-  
 distillation column"

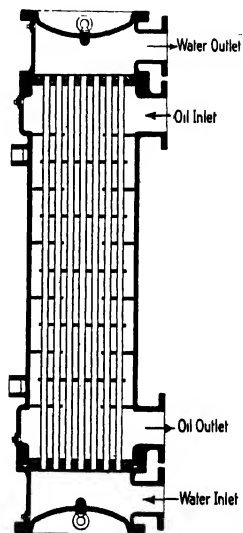


FIG. 54

Schutte and Koerting oil  
 vapor condenser.

to pass back and forth across the tubes by means of the vertical baffles of concentric cylinders, with slots placed diametrically opposite at each succeeding baffle.

Few tests are available on the above types of condenser, but those to which reference could be made show that the figures previously given in the text and tables are conservative, and may be often surpassed under advantageous conditions. More and more attention is now being given to the shell and tube type of condenser, so that rapid progress should be made.

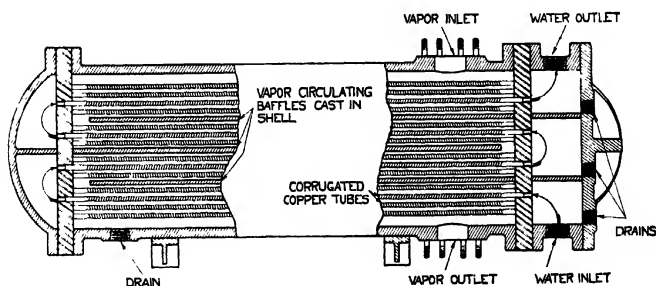


FIG. 55

Alberger Pump and Machinery Company's oil vapor condenser.

The Southwestern gasoline condenser of Fig. 56 has been used on the western coast. This apparatus involves the shell and tube principle, with interesting modifications. The vapors enter the shell at the top, descending through the unit. They are broken up by nests of horizontal tubes through which the cooling water circulates. The sectional area is comparatively small, resulting in short tube lengths which undergo only a slight amount of expansion as they are heated. Consequently unusual tightness is claimed. The water circulation is carefully controlled by operating the nests of horizontal tubes in series or parallel, as may be desired. The apparatus is well adapted for use as a dephlegmator or heat exchanger. Tests on gasoline condensation conducted at Maricopa, California, give a value of  $\rho$ , the transfer rate, of 70 to 85 B.t.u., with water consumption of 3.5 to 4 gallons per gallon of condensate. The condensates



were reduced considerably below the temperatures of usual practice, so that the water consumption could be somewhat reduced under ordinary conditions.

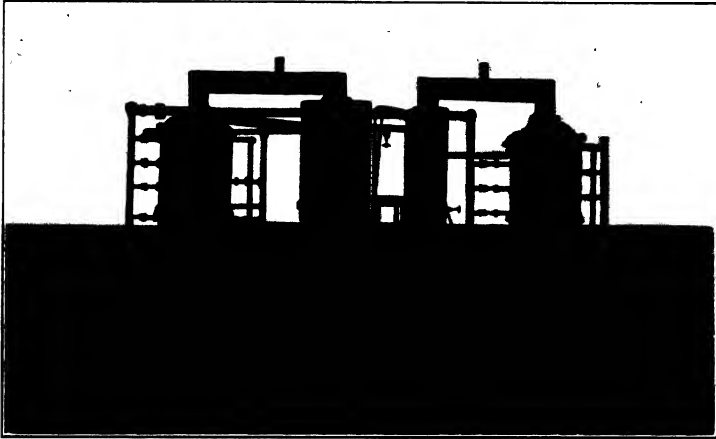


FIG. 56

Dephlegmators and condensers designed and built by the Southwestern Condenser Co.

The points to consider in the selection of a shell and tube type of apparatus, after the amount of surface is settled, are,

Durability;  
Expansion;  
Velocities.

Many of the earlier installations proved failures because of the use of brass or copper tubes, as in steam practice. All oils contain sulphur in from minute quantities up to considerable percentages. Copper will not withstand the action of the sulphur compounds. Steel, charcoal, iron and Admiralty mixture tubes have given much better service. Extra thickness of these tubes should be insisted upon.

Expansion is taken care of in several ways; by ferrules in the tube sheets, by using a floating head at one end, or by using

U-shaped tubes, both ends of a tube being expanded into one tube plate. The engineer or owner should satisfy himself that the method used will satisfactorily take care of the expansion.

The velocities of flow of the vapor and the water have a direct bearing on the heat transfer; so that (other points being equal) less surface, or a higher water discharge temperature for the same surface (with consequent lower water consumption) is possible with high velocities.

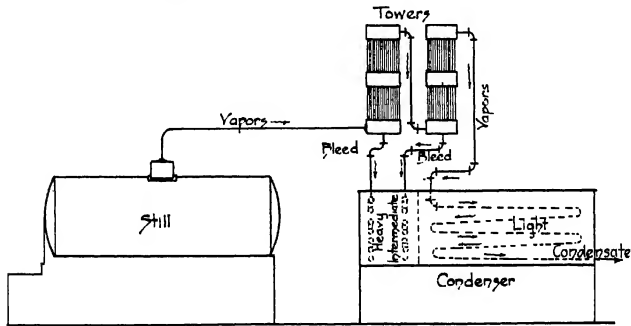


FIG. 57

Diagram of "tower" still.

Before leaving the subject of condensation, the topic of fractionating condensers should receive attention. There are different methods of accomplishing fractionation. Classified accord-

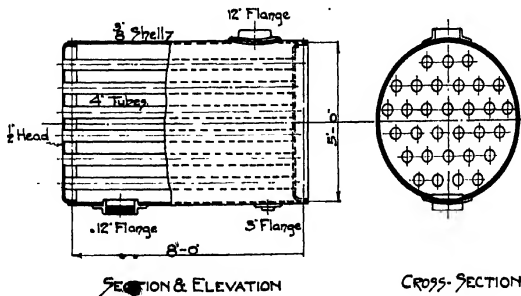


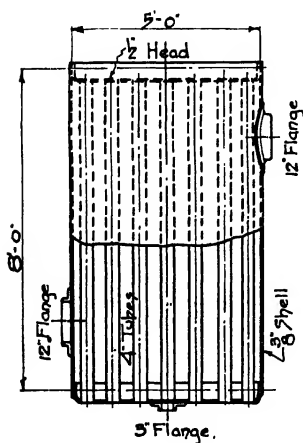
FIG. 58

Horizontal tower.

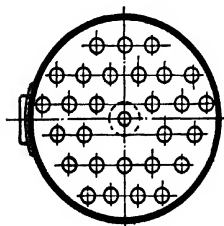
ing to the medium used to effect the initial cooling, fractional condensers may be grouped as follows:

- Aerial;
- Water cooled;
- Vapor heat exchangers.

The object of fractional condensation is always to obtain closer "cuts" of products, and hence to eliminate re-running of the distillates as much as possible.



SECTION & ELEVATION



CROSS SECTION

FIG. 59

Vertical tower.

Among the first forms of fractionating condensers were the so-called "towers." Differing in detailed design, the towers were essentially aircooled preliminary condensers in which the heavy part of the vapors was liquefied and trapped out, to be either bled back to the still or conducted through a further cooling coil as a separate distillate. One or more towers were used, with a final condenser for the light portions of the vapors. Fig. 57 is diagrammatic of a still equipped with two towers. Types of tower are illustrated by Figs. 58 and 59. In all cases, with aerial condensers, the temperature control is difficult. Different seasons and different atmospheric conditions tend to produce very uneven results. The Gray tower of Fig. 60 is an improvement, the circulation of air (and hence the temperature) being controlled by the dampers.

Another type, not often used to-day, is the aerial condenser constructed of pipe and fittings.

This type is most erratic in performance and cannot be recommended unless fully protected from rainfall.

The heat transfer rate from the hot surfaces of air-cooled condensers may be taken at  $\rho = 2.7$  B.t.u. The amount of sur-

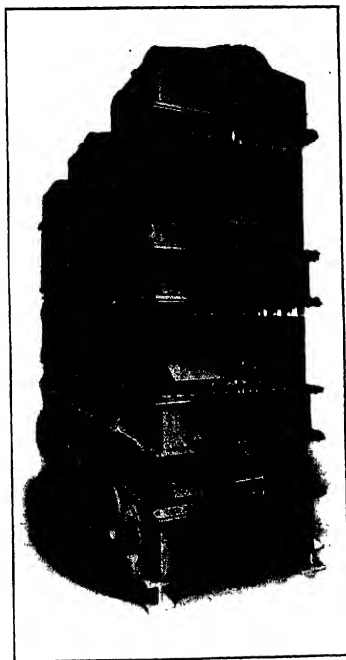


FIG. 60  
Gray Tower.

face to be provided is very difficult to estimate closely. The proportion of heavy distillate carried over with the lighter part, and the precise heat content, cannot be determined accurately in advance. For this reason results from some actual installations will best serve as a guide.

It is obvious that the temperature of the light fraction, still in the vapor state, after passing through one or more towers, is considerably reduced. This reduction warrants a reduction

in the surface of the final water-cooled or "light" coil, in proportion to the heat content removed. The so-called "heavy" coil, through which the bleed from the first tower passes, and the intermediate coil, through which the bleed from the second tower passes, are only for the purpose of cooling the condensate to a suitable temperature for handling. The surface necessary for these cooling coils depends upon the size of, and the results obtained from, the towers.

If submerged coils are used, the usual custom is to place the heavy and intermediate cooler coils in a compartment separate from that containing the final light worm, because the water requirements, both as to volume and as to temperature, are quite different.

Water cooled preliminary condensers have been used. They are designed like ordinary submerged coils, previously discussed.

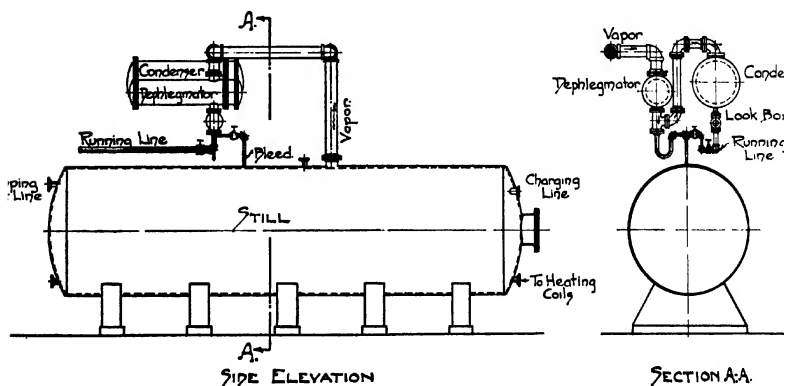


FIG. 61

Steam still with tubular dephlegmator and condenser.

A modification of this type is the shell and tube condenser, for holding back heavy ends, prior to final condensation of the vapors in a second shell-and-tube apparatus. This arrangement offers the possibility of close temperature control, since insulation will render such control dependent only on the amount of

circulating water admitted. A design for a still using superheated steam for naphtha rectification is shown in Fig. 61.

Exchange of heat between the vapors and the oil going to the still is a form of partial condensation which has proven highly economical. This subject will be discussed in detail in Chapter IX.

One of the best examples of a fractionating condenser is that of the Trumble system, U. S. patents 996736, 1002474 and 1070361 previously discussed. Fig. 62 illustrates in a general way the action of these condensers.

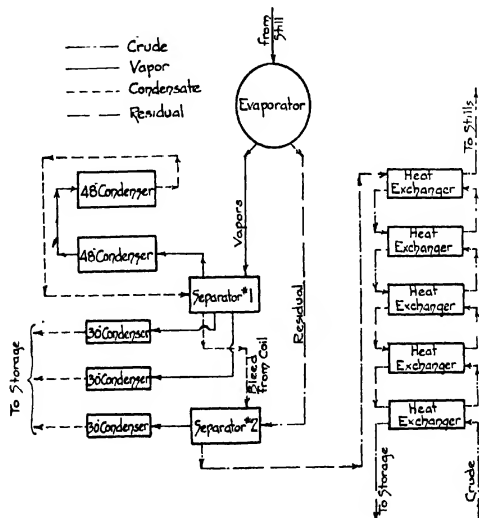


FIG. 62

Diagram of Trumble condensers and exchangers.

In this system, several cuts are taken off, which approximate those obtainable by re-running the distillates; with a very high record for overall efficiency.

The question of fractional condensation is one of great importance to the refiner, and one which is now receiving careful attention, with a possibility of radical improvement in the near future.

The third type of condenser is that where direct contact or mingling of the condensing medium and vapor takes place. The ordinary barometric jet condenser may be adapted to this work. The Fleming condenser, Fig. 63 (U. S. patents) is of this type. One objection often raised is the possibility of an emulsion of the condensate in the water. Condensers of this type are successfully handling distillates as low as 27° B. They are therefore adapted to the majority of refining problems. With jet condensers, the combined distillates and water must leave the chamber at a temperature not higher than that which is considered satisfactory for the distillate itself. This fact eliminates counter-flow and any such water outlet temperatures as have been previously discussed. With water at 60° and a distillate and water outlet temperature of 90°, approximately 6 gallons of water are necessary per gallon of gasoline distillate, when there is no use of steam during the distillation; and with 70° water, 9 gallons are necessary per gallon of distillate. This high water consumption, while often serious, should be balanced against the high first cost and consequent high overhead charges of the other types of condenser. The cost of a jet condenser will not exceed 2 or 3 per cent. of that of the tank and submerged coil type.

In conclusion, a brief summary of the condensing problem is as follows: The submerged continuous coil is the oldest of condensing equipments. Refiners are partial to it for three primary reasons; safety, ability to resist corrosion (cast iron pipe of course being used), and familiarity with it. On account of the large quantity of water in the box or tank, a failure of the water supply is not dangerous from the standpoint of escaping uncondensed vapors. Sufficient time is available, before the water box heats up, to shut down the still. It is claimed that the shell and tube apparatus does not offer this margin of safety. Since the shell and tube type of condensers are best adapted for continuous stills running the lighter distillates, adequate heat exchangers are then possible and will in themselves afford some reduction of risk. Steam is usually present, and the shutting off

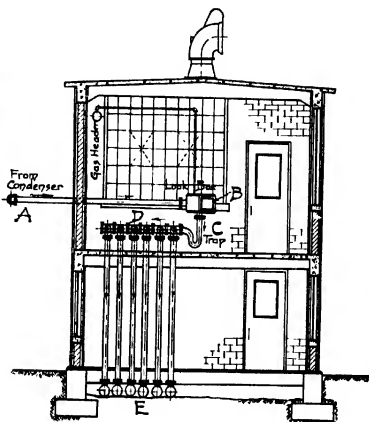
of fires and introduction of top steam will check the vaporization quickly. The long service realized, with no accidents of any importance, is further evidence that the shell and tube type is acceptable from the safety standpoint.

More trouble will undoubtedly be experienced from corrosion with this type than with the submerged coil of heavy cast iron pipe. The great advantage in first cost, smaller surface required and water saved, renders the slightly increased maintenance cost for occasional retubing of small moment.



FIG. 63

Fleming jet condenser.



CROSS SECTION OF RECEIVING HOUSE

FIG. 64

Section of receiving house.

Custom or familiarity with the early types cannot be considered a real reason for their continuance in competition with the more efficient types.

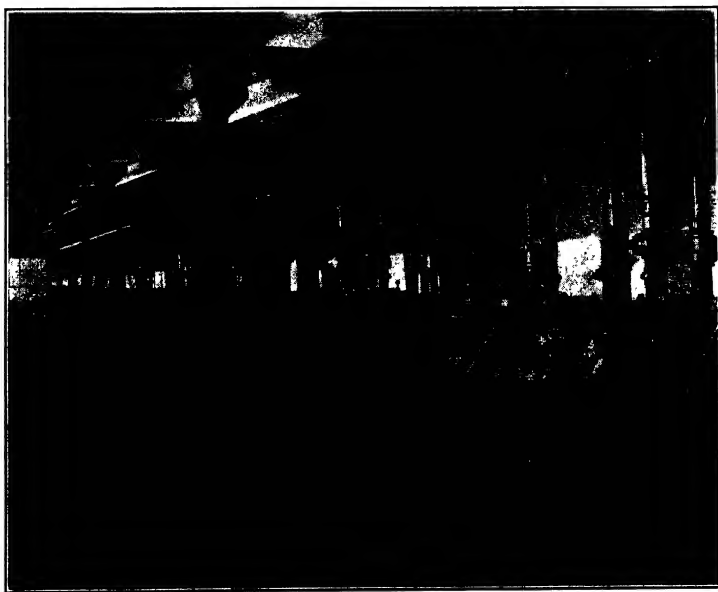
The cast iron submerged continuous coil is still the most satisfactory on batch stills running to cylinder stock or coke, and on the heavier end of continuous still batteries. The parallel coil finds a field with the stills (either steam or fire) used



for removing light fractions. For batch stills employed for the later taking off of heavier cuts, the parallel coil is not so satisfactory.

Shell and tube apparatus is well adapted for topping stills, or for the first light distillate stills of continuous batteries.

Jet condensers are of advantage where low first cost is important, and should receive consideration in connection with stills running only light distillates overhead, where there is an abundance of cooling water, since the decreased overhead and maintenance costs may more than offset the cost of pumping more water.



(Courtesy C. B. Roberts Eng. Co.)

FIG. 65

Interior of receiving house showing turret type "look boxes." Fall River refinery of New England Oil Co.

While not part of the condensing system proper, the receiving house, also termed the "tail" or "running" house, is so closely associated therewith that it may well be considered in this chap-

ter. Fig. 64 is a section of the typical construction. Individual lines, *A*, from each condenser enter the look-box, *B*, one for each still (or for each cut from each still if towers or fractionating condensers are used). After passing through the gas trap, *C*, the condensate enters header *D*. This header is made up of three way cocks or of branch tees and valves (or cocks) and each outlet connects with another header, *E*, manifolded into each of the headers *D* under each look-box. Each of the headers, *E*, leads to a separate receiving or running tank. The entire distillation process is controlled from the receiving house. All of the streams are under observation in the look-boxes and means for testing the streams are provided. As the streams change in character, they may be thrown from tank to tank by the valves or cocks of header *D*. In batch operation, more manipulation is necessary than when continuous distillation is going on, since in the latter case the character of the stream from any one condenser coil is fairly constant.

The gas may be removed by a header over the look-boxes,

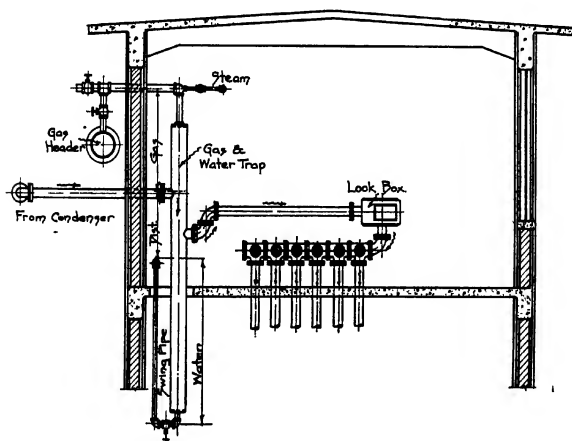


FIG. 66

Arrangement of gas and water trap in receiving house.

leading to a rotary gas exhauster and piping system to a gas holder, and may then be used for fuel or in internal combustion

engines. A type of combined water and gas trap often employed is illustrated by Fig. 66.

A form of receiving or look-box sometimes used is the "tur-

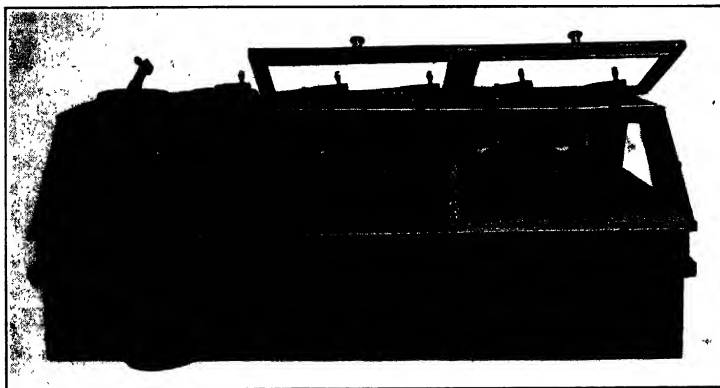


FIG. 67

Turret type look box and manifold.

ret" system of Fig. 67. Fig. 68 shows another type of similar characteristics. The advantages of these two types are, economy of space and saving of pipe and fittings. The upper headers

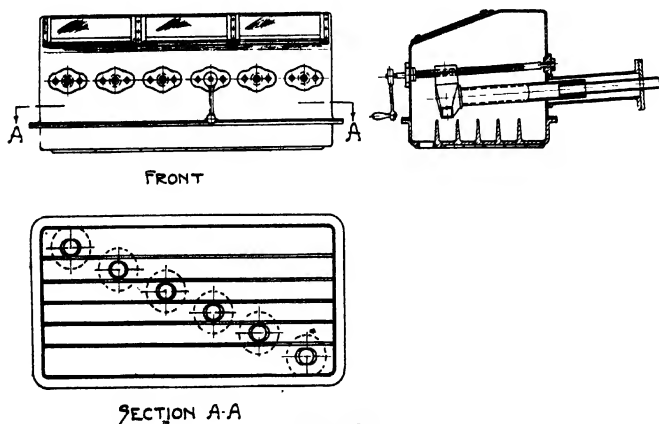


FIG. 68

Spout and trough type look box and manifold.

and valves are entirely eliminated and the stream directed by the relative positions of the opening in the revolving box and the discharge spout. The various troughs connect with the headers leading to the receiving tanks. While decidedly economical, trough type look-boxes are open to one important objection, The troughs will maintain an efficient separation of the cuts under ordinary operation. A little water entering the still, by accident or from other reasons, sometimes causes the oil to come over through the condenser worms in excessive volume. This is termed "puking" by the stillmen. When such occasions arise, the trough type boxes will fill above the partitions which normally divide the stream, with the result that all of the receiving tanks supplied by any particular box are contaminated. With individual look-boxes, one for each condensate line, not more than one tank will be affected. Since the contamination is often serious, and frequently necessitates re-running the contents of the receiving tanks, the importance of this defect in trough type boxes is apparent.

## CHAPTER IX

### HEAT EXCHANGERS

Residual exchangers—Vapor heat exchangers—Modern tubular vapor heat exchangers—Exchangers and scrubbing towers for steam stills.

Nowhere is there better opportunity for the conservation of waste heat than in the distillation departments of oil refineries. The flue gases themselves offer possibilities in this direction, as already outlined in the chapter on stills. The subject will be further discussed in connection with refinery power houses. This present chapter will deal with methods of utilizing the heat contained in the vapors and in the residuals from the stills, and will suggest similar economizing modifications in other stages of process work.

For the purpose of the present discussion, exchangers for stills may be classified as *vapor exchangers* and *residual exchangers*. The batch still does not lend itself readily to economy

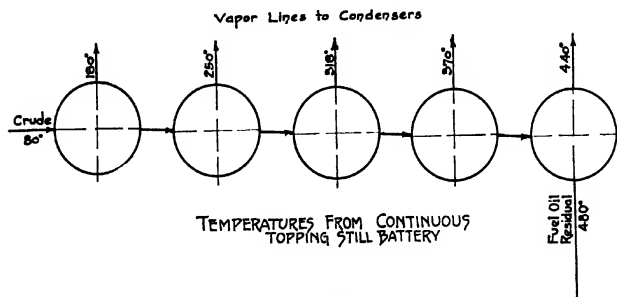


FIG. 69

Diagram of temperatures of vapors and residual from continuous stills.

in heat interchange, because, during the operation there is no oil flowing to the still; and when the run is over, the necessity of removing the residual quickly to make way for a new charge outweighs the desirability of making use of the heat contained.

Fig. 69 represents a battery of five stills arranged to run continuously, and shows the temperatures which might be expected at the various outlets when reducing a typical Mid-Continent crude to a fifty per cent. bottom. The opportunities for economy are obvious. By using a residual exchanger and vapor exchangers in series, the temperature of the entering crude may be greatly increased. This will result in a saving of fuel, the throughput will be increased and (a factor often overlooked) the necessary amount of condensing surface or of water required will be reduced.

Many refiners take advantage of the heat in the residual. An example of the resulting economy follows:

Assume a battery of stills to be running 4,000 barrels of crude per day to a 50 per cent. bottom, as in Fig. 69. There will be discharged 2,000 barrels at a temperature of  $480^{\circ}$ . This must be cooled prior to further handling. If this residual at  $27^{\circ}$  B. is cooled to  $120^{\circ}$  F., there will be given up 112,400,000 B.t.u. in the course of the day's run. This (if fully transferred) is capable of heating the incoming crude to  $278^{\circ}$  F. When, however, the working conditions are considered, it is apparent that this ideal temperature will not be attained. In the first place, radiation losses will be encountered; and in the second place, the rate of heat transfer in apparatus adapted to this kind of work is so low that an excessively large exchanger would be needed to utilize all of the heat available. The mean temperature difference is  $112^{\circ}$  F. Assuming an exchange rate of  $\rho = 6$  B.t.u., an exchanging surface of 6,950 square feet would be required. This would be prohibitively large and costly. It is feasible, however, to install residual apparatus of practicable size and cost, and thus to raise the ingoing crude to a temperature of  $190^{\circ}$  F. or slightly higher, which will imply a saving of 25 to 28 per cent. of the heat otherwise necessary for distilling 50 per cent. from the average crude. Expressed in terms of the coal pile, for a 4,000 barrel example, 14 tons of coal per day would be saved. The above figures are all on the basis of skimming crude oil to a 50 per cent. residual. It is of course apparent that if the

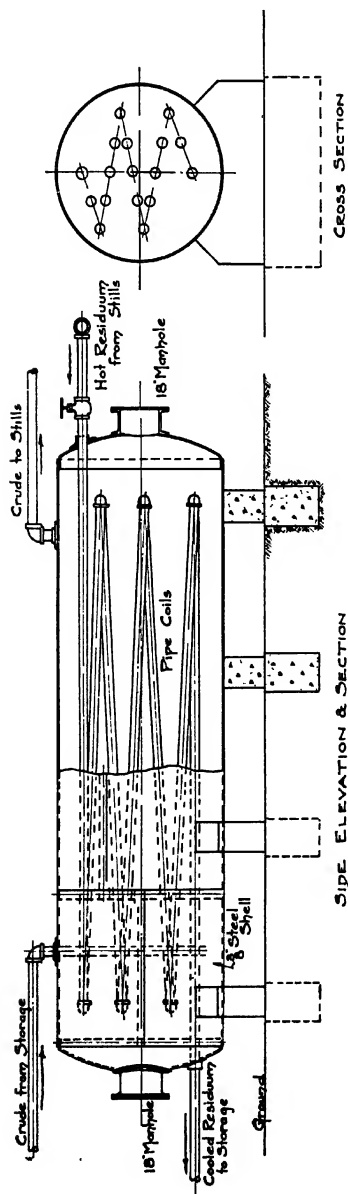


FIG. 70

Shell and coil residual exchanger.

oil is "run farther down," that is, reduced to a smaller percentage of residual, the saving will be less, because a smaller quantity of hot oil will remain to give up its heat content.

For the exchange of heat from the residual oil of a continuous distillation process to the cold raw stock entering the first unit, apparatus of three different types is in use. Perhaps most general, because most easily made, is the tank and coil type, Fig. 70. The hot oil from the last still is pumped out through a continuous coil of pipe submerged in a tank, through which tank the cold oil is pumped to the first unit. The rate of transfer of heat is very low, the surface-to-volume ratio being low and the velocities, particularly that of the cold oil, being very slow. Coefficients of  $\rho = 6$  or 7 B.t.u. are about all that can be expected. The introduction of baffles to produce higher cold oil velocities will help materially.

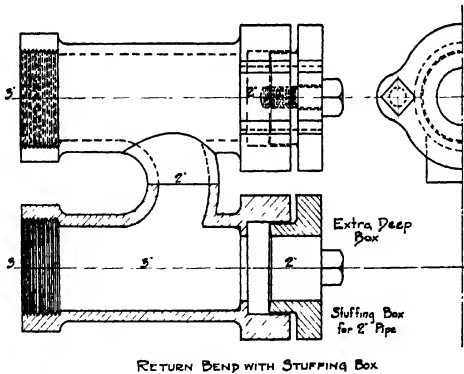
The shell and tube type of exchanger is well adapted to this work and many of the commercial forms of this kind of exchanger can be used with profit. The residual exchangers of the Trumble process are of this variety. By proper baffling, and by employing tube sizes to produce minimum velocities of  $1\frac{1}{2}$  feet per second, transfer coefficients of  $\rho = 35$  to 40 B.t.u. have been attained. A figure of 25 to 30 B.t.u. may be expected in usual practice. Fig. 71 shows a shell and tube apparatus adapted to residual heat exchange.

Double pipe apparatus is also used. The velocities with practicable pipe sizes are lower than in shell and tube exchangers and hence the heat transfer rate is also lower. However, this apparatus can be easily assembled from stock pipe and a few special fittings, and is also easily repaired. A rate of exchange of 14 to 18 B.t.u. may be expected. The popular sizes of pipe are 2 inches within 3 inches and 3 inches within 4 inches. Figs. 72 and 73 give details of the fittings and of a 15 run assembly for a 2 inch to 3 inch exchanger. The fittings closely approximate those used on the well-known double pipe apparatus for ammonia condensers of refrigerating machines. They are heavy on account of the hot oil. For temperatures of 450° F. or above,





steel fittings should be used for the first runs. It will be noted that the stuffing boxes are made of extra depth on account of the penetrating nature of the hot liquids.



RETURN BEND WITH STUFFING BOX

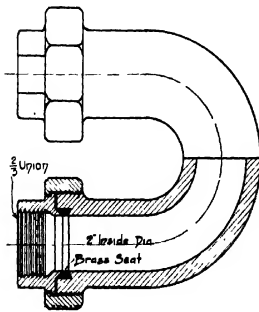
RETURN BEND WITH  $\frac{2}{3}$  UNION

FIG. 72

Details of fittings for double pipe heat exchanger.

Fig. 69 shows that a large amount of heat passing through the vapor lines remains to be abstracted by the condensers. Much of this heat may be removed by vapor heat exchangers. The earliest installations in the United States for this purpose were adaptations from European practice. Fig. 74 (after Engler) illustrates in general the type of apparatus. The essential part consists of a cylindrical shell mounted above the level of

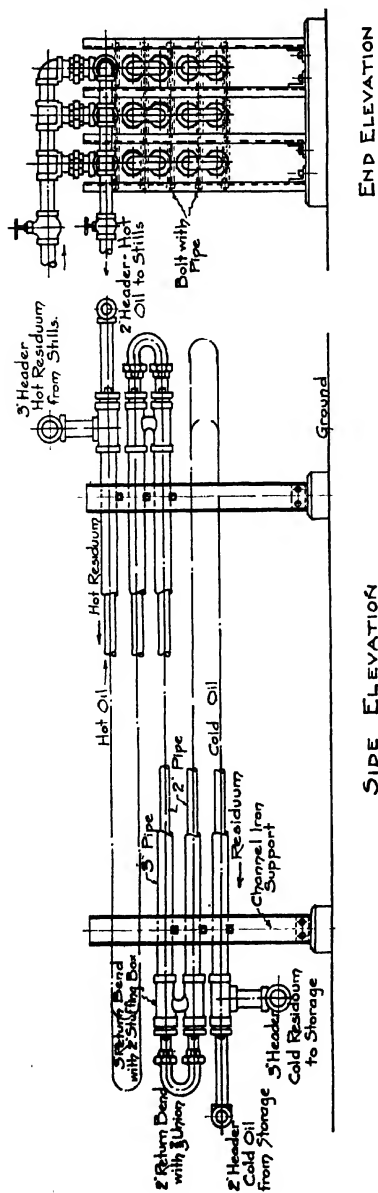
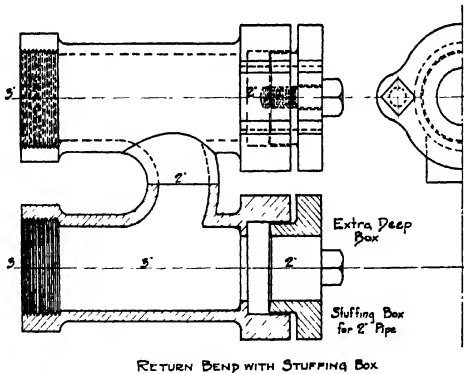


FIG. 73  
Assembly of double pipe heat exchanger.

steel fittings should be used for the first runs. It will be noted that the stuffing boxes are made of extra depth on account of the penetrating nature of the hot liquids.



RETURN BEND WITH STUFFING BOX

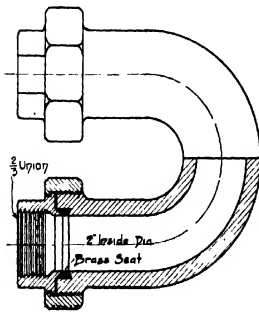
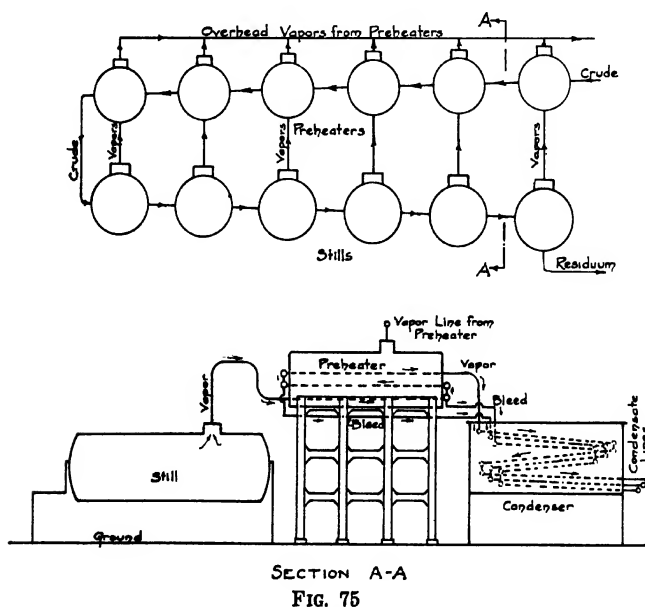
RETURN BEND WITH  $\frac{2}{3}$  UNION

FIG. 72

Details of fittings for double pipe heat exchanger.

Fig. 69 shows that a large amount of heat passing through the vapor lines remains to be abstracted by the condensers. Much of this heat may be removed by vapor heat exchangers. The earliest installations in the United States for this purpose were adaptations from European practice. Fig. 74 (after Engler) illustrates in general the type of apparatus. The essential part consists of a cylindrical shell mounted above the level of

the still. The shell contains runs of pipe. The crude oil passes through these shells in series on its way to the first still of the continuous battery, while the vapors from the stills pass through the inner pipes, giving up their heat to the entering crude oil. As the vapors are cooled, partial condensation takes place, and this condensate may be trapped if desired, giving two or three streams of products from each still. Fig. 75 is diagrammatic of this type of apparatus on a battery of six continuous stills. There are light, heavy and intermediate coils for each still. These, in addition to the distillate collected from the preheaters, yield in all nineteen fractions from the battery.



Arrangement of vapor heat exchangers on a battery of continuous stills

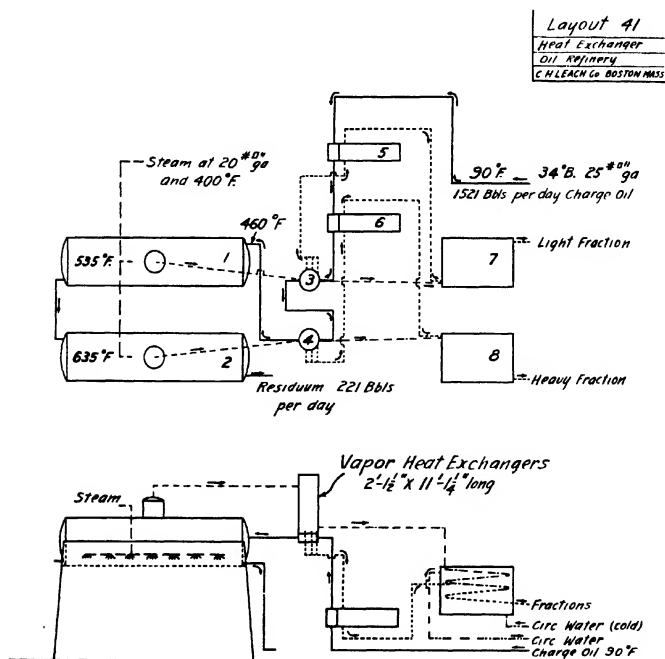
It has been found that for a continuous still battery running 4,000 barrels per day to a 35 per cent. bottom, a total of 3,600 square feet of exchanging surface will increase the temperature of the charge fed to the first still from 90° to about 300° F.,

removing therefrom 12 per cent. of gasoline vapors, and effecting a fuel saving of about 20 per cent. The commercial efficiency is apparent. In addition, fractional condensation is possible and the water requirements are reduced. The surface of the water condensers could be reduced, but this step is of doubtful economy. There are times when the vapor heat exchanger may be out of service; and if the condenser surface is reduced, the rate of distillation for the battery would be then retarded. It would, therefore, seem advisable to retain the full condenser surface and use less water.

There are several points of criticism in connection with preheating apparatus of the type above described. The first cost is high, the volume of crude oil in each unit considerable and the transfer efficiency low. Some idea of the cost may be obtained from the drawings. The exchangers must be set high in order to drain through the regular condenser boxes, and expensive structural supports are necessary. The amount of crude contained in a series of these elevated exchangers is large and constitutes a source of danger in case of fire. The low transfer efficiency is explained by the low velocities of both oil and vapor. Tests indicate that a transfer of  $\rho =$  two to three B.t.u. is about all that can be expected. Despite these objections, such an installation will nevertheless give excellent returns upon the investment.

The disadvantages of the adapted European preheaters have led to experiments with more efficient apparatus of the tubular type. Fig. 76 shows an application of the Alberger Heater Company's exchangers, well suited to this work. Other makes of surface condensers have also been used with success. In this apparatus, the oil is passed through relatively small tubes with the vapor counter-current in the shell. One or more passes per unit may be used. Advantageous velocities are attainable, and transfer rates of 13 B.t.u. or better have been attained. In addition to the increased transfer efficiency, there is the advantage that only a small quantity of crude is present in each unit, with consequent greater safety in case of fire. The cost, while higher on a

square foot basis, is relatively low on a capacity basis, when compared with the system previously described. An installation of approximately 900 square feet of tubular type exchangers is reported to have increased the temperature of the ingoing oil on a battery running 1,500 barrels per day, by a total of 250°



Heat Balance for Heat Exchangers Nos 3, 4, 5 & 6 in BTUs per hour above 90°F

	Debit	Credit		
	Received from Stills	Recovered by Charge Oil	Extracted by Condenser Box	Radiation
Heat in Oil Vapor & Condensate	5225444	3432712	1687732	105000
Heat in Steam & Condensate	1006092	44875	359217	2000
	6231536	3477587	2646949	107000

FIG. 76

Diagram and results from vapor heat exchangers applied to stills re-running stock.

F. In this case, however, the oil had been previously topped, so that the vapor temperatures were above those encountered in crude distillation. Moreover, the overhead from the stills amounted to 95 per cent. of the throughput; an unusual condition and one particularly favorable in work of this kind.

In considering the design of exchangers of the above type, it is very important to investigate carefully the method used to take care of tube expansion. Temperatures of 400° to 500° are often encountered and suitable provision for such temperatures must be made. Floating heads, flexible diaphragm heads, and ferrules, have all been used with success. Tubes expanded into rigid tube plates are sure to give trouble if temperatures are high. Tubes should be not less than No. 16 Birmingham gauge steel. Although the steel will be corroded on the vapor side to some extent, corrosion will be very slow after getting below the surface of the metal, and tubes of the above thickness will have a satisfactory life. Copper or brass tubes should be avoided. Aluminum, admiralty mixture and monel metal have been used with good results. Another detail to consider is the method for relief of evolved vapors if the temperatures attained exceed the boiling points of the oil. This may be readily accomplished by introducing an expansion chamber or separator in the flow line, removing the vapors to a condenser and allowing the oil to continue to the stills or to further exchangers. On the vapor side, drips may be introduced for fractionating, if desired.

The earlier installations of vapor heat exchangers of the tubular type were confined to steam stills. A steam still assembly with tower and exchanger is shown in Fig. 39. Details of the exchanger are illustrated by Fig. 77. In this case, the temperatures are not excessive and the tubes may be expanded directly into tube sheets. This type of exchanger is not as efficient as the modern tubular type described above and may be expected in the future to be supplanted by that type. It does offer, however, a relatively inexpensive installation with undoubted economy.\* The surface desirable is from 0.5 to 0.6



square feet per gallon of overhead distillate per hour. With about this surface, the average of several tests shows 43 per cent. saving in steam consumption and 29 per cent. increased capacity.

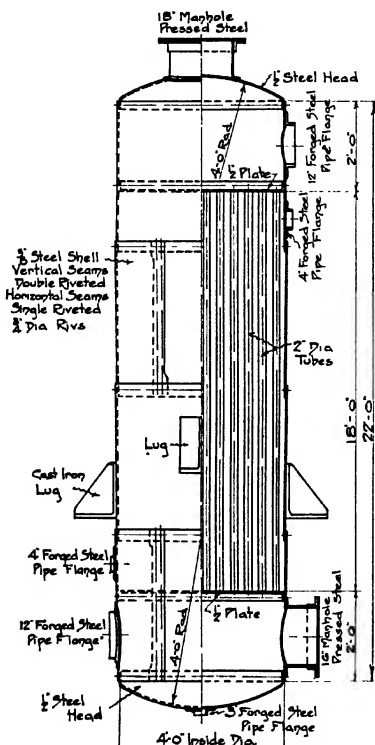


FIG. 77

Vapor heat exchanger for steam still.

The scrubbing tower, in addition to being a dephlegmator, is also a very efficient heat exchanger. It finds its greatest use in those stills employed for re-running a light distillate for gasoline or naphtha. Fig. 78 is a tower adapted to a fifteen hundred barrel steam still. The feed is introduced at the top and divided into fine streams by the filling materials. The ascending vapors come into intimate contact with the feed, and the heavier por-

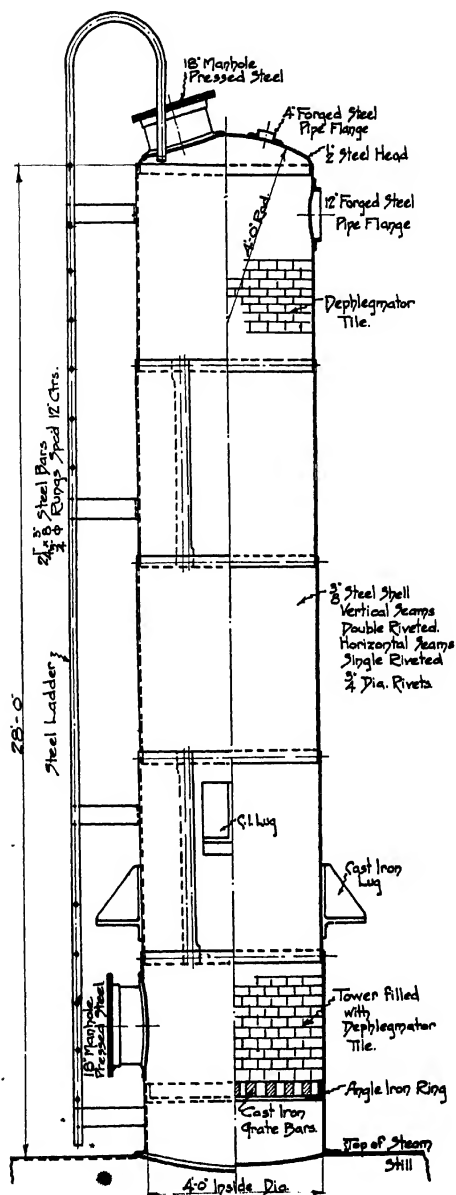


FIG. 78

Dephlegmator or packed scrubbing tower for steam still.

tions of higher boiling point are condensed and fall back to the still. The descending spray abstracts the heat from the vapors and its light constituents are evaporated, while the heavier and greater part proceeds on down to the still for further vaporization.

The average batch still which is used on the class of work above outlined cannot realize these economies without a change in the method of running. This may easily be accomplished, however, in either of two ways. Baffles may be inserted and the still run continuously, drawing the heavy bottoms off at the end furthest from the tower. This method lends itself readily to straight steam distillation<sup>1</sup> but it is not as easily controlled in a combination still, i.e., one using both fire and steam: which type is becoming more and more popular as the boiling points of the gasoline fractions are raised to meet growing demands. A method of operation adapted to both types of stills is that of "semi-continuous" running. By this method, a small amount of charge is placed in the still and distillation started. The still is then fed continuously and the bottoms, or residual, allowed to accumulate until the capacity of the still to hold such bottoms is reached; when the process is stopped and the still emptied. In this way the advantages of the vapor heat exchangers approximate those possible with continuous distillation.

<sup>1</sup> See Frasch, U. S. patents 845,456, February, 1907, and 845,735, February, 1907; and Ellis and Meigs, "Gasoline and Other Motor Fuels," p. 128.

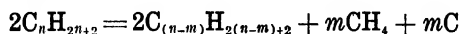
## CHAPTER X

### CRACKING

Theory—Stocks used—Various processes—Practical considerations—Use of aluminum chloride

The pyrogenic decomposition of petroleum with the consequent breaking up of the molecules and the production of both lighter and heavier hydro-carbons is termed "cracking." In the terminology of the industry "cracking processes" are those designed to utilize the above decomposition for the conversion of heavier oils into the more valuable gasolines and naphthas. All petroleum hydro-carbons have a characteristic temperature above which the cracking reaction takes place. This temperature varies for the different cuts from a given crude and for similar cuts from different crude oils. For the gas oil and fuel oil distillates now in use as stock for cracking operation the temperature necessary to cause the reaction is usually between 550° F. and 600° F.

Cross<sup>1</sup> offers the following formula in explanation of the cracking reaction:



In the case of Pentadecane ( $C_{15}H_{32}$ ) the application of this formula gives:



Pentadecane = Octane + Methane + Carbon.

In this example a heavy oil of 0.807 gravity and 270° C. boiling point is cracked to yield a light hydro-carbon, octane, of 0.718 gravity and 125.5° C. boiling point along with the fixed gas methane and free carbon. Cross states that the above is only an indication of what takes place and that in practice oils of higher boiling points are also produced at times while the quan-

<sup>1</sup> Bulletin No. 16 of the Kansas City Testing Laboratory.

tity of gas evolved is very small. Owing to the complex nature of the hydro-carbon compounds no exact definition of the reactions which occur has been offered. Fortunately this is not necessary to an appreciation of the commercial results of cracking processes.

As a general rule the simpler hydro-carbon compounds are more stable at high temperatures than those of greater molecular weight. When exposed to heat olefines or unsaturated compounds are generally conceded less stable and naphthenes more stable than saturated paraffin hydro-carbons of the same molecular weight. These variations account for the differences between the cracking temperatures of various oils of general similarity. It is generally conceded that certain oils such as those from California and Mexico will break down more readily with consequent greater production of fixed gas and carbon than an oil of paraffine base such as that from Pennsylvania.

The great bulk of the stocks which are cracked for yields of gasoline is composed of gas oils and the stocks distilled from crude oil between that cut and coke. Mention was above made of the greater stability of the simpler hydro-carbon molecules. There are two essential factors in the cracking operation; temperature and the time through which the molecule is subjected to that temperature. Pressure is corollary to the temperature. The simpler hydro-carbons require higher temperatures and longer time elements than the more complex ones of greater specific gravity. Such stocks as kerosene distillate are therefore seldom cracked on a commercial scale.

It follows conversely that heavy residual oils should crack very easily and such is found to be the case in practice. There is one serious objection to such procedure. Such oils crack so rapidly and easily that the problems of fixed gas losses and carbon deposition become acute. In commercial operation the gas is a financial loss and the carbon deposits reduce the length of run and hence increase the percentage of idle apparatus time and decrease the capacity of the apparatus.

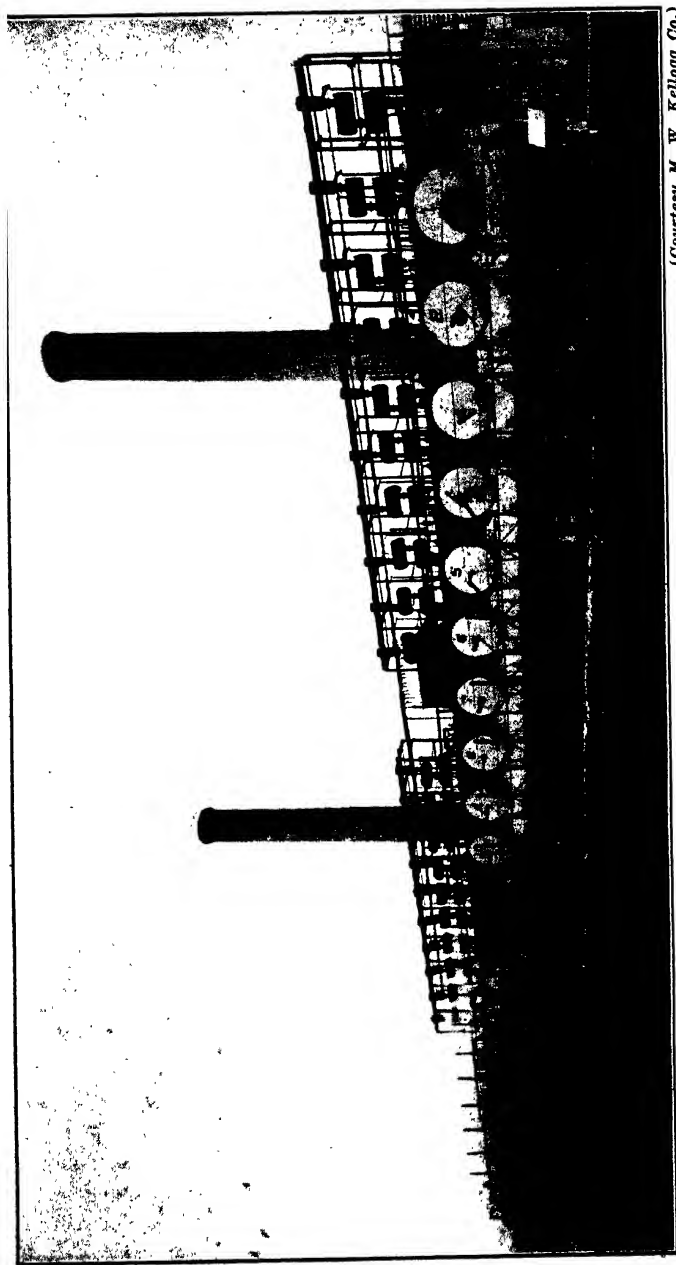
For these reasons attention is largely confined to cracking

of overhead distillates with boiling points ranging from 450° F. upwards. The higher the boiling points the better the commercial results providing however that the oil is an overhead distillate.

This fact is an economic advantage. While at times it may be profitable to crack kerosene distillates notwithstanding the greater expense involved, this product has a great deal broader and steadier market than the gas and fuel oils and heavier distillates. It also commands, even under the most adverse markets, a higher price than the last named stocks. Fuel oil may be profitably cracked by first reducing it to coke or flux and processing the overhead distillates therefrom. By this method the troubles due to excessive carbon deposition may be avoided.

When reducing a crude oil or a residual fuel oil to a very heavy gravity in the ordinary still this residual termed flux has an unsatisfactory viscosity and too high a cold test for use as commercial fuel oil. One of the characteristics of cracking distillation however is the low viscosity and cold test of the residual. Even when a cracking process is operated on the re-cycling principle as later discussed there is available a considerable residue of very good quality for fuel oil. This stock serves admirably for blending with the flux from the crude to produce a commercially acceptable fuel oil.

Historically, cracking dates back to the early years of the nineteenth century when the formation of volatile compounds by cracking animal oils was discovered. These early discoveries were regarded merely as scientific phenomena of no commercial value. In the early days of the petroleum industry attention was paid to increasing the yields of illuminating oils, then the most valuable constituent of the crude. Atwood, U. S. patents 28246, 1860, describes a method of increasing the yield of illuminants by cracking distillation at atmosphere pressure. Young, British patent 3345, in 1865 is apparently the first investigator to use pressure to increase the temperature of distillation. Benton, U. S. patent 342564, 1886, also applied pressure. The above two patents released the pressure prior to condensing the evolved



(Courtesy M. W. Kellogg Co.)

FIG. 79  
Battery of high pressure "cracking" stills.

vapors. The Dewar-Redwood process (U. S. patents 419931 and 426173, 1890, and various British patents) was the first to both distill and condense under pressure.

Since these early pioneers the demand for gasoline has resulted in many different processes. Few have claims to originality and fewer still have made a commercial success.

The systems advocated and in commercial use may be broadly classified as *cracking in the vapor phase* and *cracking in the liquid phase*.

Cracking in the *vapor phase* consists in vaporizing the oil and then producing the reaction by the addition of heat, or of heat and pressure together. The well-known oil gas plant methods illustrate vapor phase cracking dependent upon heat without pressure. Rittman and Greenstreet use both high temperature and pressure. Vapor phase cracking is not used to any great extent by the large refiners. The usual difficulties which have retarded the development of vapor phase cracking are the relatively high percentage of unsaturated hydro-carbons in the product and the severe treatment accorded the apparatus. The first is probably due to lack of exact control. Oil vapors have a low specific heat and the tube temperatures are very high which conditions not only aggravate the problem of control but are injurious to the apparatus. The vapors with low specific heat will not carry away enough of the heat applied to tube or retort walls to prevent overheating with consequent liability of rupture. This condition is further aggravated by the deposition of free carbon on the hot walls of tubes or retort.

As a result practically all successful commercial processes in present use operate on the liquid phase principle. The first commercially successful process in the United States is that of Dr. W. M. Burton in use by many of the Standard Oil Companies. This system, original U. S. patent 1049667, 1912, has been modified and improved by further patents granted to Dr. Burton and others.

Other successful commercial liquid phase systems are those of Cross, Dubbs, Fleming, Isom, Coast, Emerson and Holmes-



Manley. It is beyond the scope of this volume<sup>1</sup> to treat in detail the above systems or the many others proposed and in course of development. Brief descriptions with such results as are available for publication are offered.

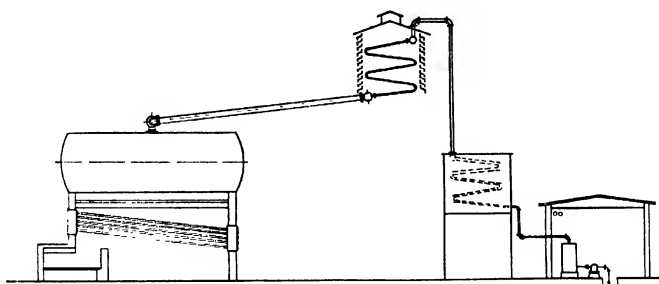


FIG. 80

Diagram of Burton-Clark still.

A typical modified Burton plant consists of a horizontal shell 10 feet in diameter and 30 feet long. Suspended by front and rear headers, very similar to the arrangement of a water tube boiler, are forty-five 4 inch tubes. These tubes are exposed directly to the hot furnace gases. The shell itself is protected. From a vapor outlet tee on the shell, two 8 inch vapor lines are inclined upward to an aerial condenser containing approximately 500 feet of 4 inch pipe. Following the aerial is a water cooled box about 10 by 10 by 14 feet. The coil reduces in the box, from 4 inches to 2 inches in diameter. The gas is separated from the condensed distillate, still under pressure, in a receiving drum. A diagrammatic sketch is given in Fig. 80.

E. M. Clark, U. S. patents 1132163 and 1129034, has connected the stills in batteries as shown in Fig. 81. A, A, are the receiving drums, one for each still. Each drum is connected to high and low pressure gas lines, *H* and *L*. Line *L* leads to a gas holder to accumulate the gas for fuel. Line *H*

<sup>1</sup> For a complete and detailed treatment of the subject, the reader is referred to Ellis and Meigs, "Gasoline and Other Motor Fuels," D. Van Nostrand Co. 1920.

is dead ended except for a relief connection controlled by valves, 5, into the low pressure gas line, *L*. Each drum is connected through a meter, *M*, to the distillate storage discharge line, *D*, and also to an emergency line, *E*. It is possible to control an entire battery by the valves 5.

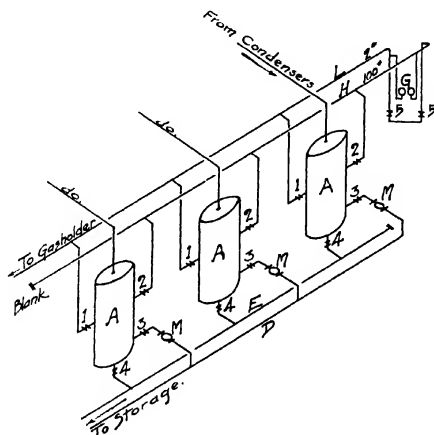


FIG. 81

Multiple control of pressure stills. (Clark patents.)

In operation, a single still is charged and fired, with valves 2 and 3 set against it. Valve 1 is open at the start but is closed as the still approaches the running temperature. The closing of valve 1 causes a pressure to be built up in the still, and by gradually opening valve 2, the unit can be "cut in" with the other stills. Valve 3 is then opened sufficiently to allow the distillate formed to be discharged into pipe *D*, leading to storage. After a run is completed, the steps are reversed in order to take the still off the system.

The stills are operated on the batch and feed principle. The charge is about 12,500 gallons. While running, an additional 10,000 gallons is fed in through the vapor line to make up for the portion of the charge distilled over. A point is finally reached where the deposition of carbon requires shutting down and

cleaning. The length of run is from 48 to 60 hours. The entire cycle, including time to charge, fire, cool and clean, is said to vary from 62 to 74 hours.

Typical results on a mixed gas oil obtained from several different crudes are reported as follows:

Gravity of charge .....	28° B.
Gravity of feed .....	20° B.
Light cracked distillate .....	60 per cent.
Residuum .....	37 per cent.
Loss .....	3 per cent.

Upon re-distillation the light cracked distillate yields 52 per cent. of gasoline stock, which, after treating and blending becomes a commercial product. This is equivalent to a 31.1 per cent. yield of gasoline from the throughput.

The results from the Burton process may be taken as fairly typical of those from most of the processes in use today. Two general avenues of approach have been followed in efforts to improve upon these results, first to increase the rate of heat transfer and second to retard the carbon deposition and hence reduce the idle still time.

The Isom process is a development of the first method. This process (U. S. patent 1285200) is based on the forced circulation of oil through a bank of vertical tubes exposed to the furnace gases. After passing through the tubes the oil enters an overhead separating drum and is then re-circulated through the tubes by a special type of pump. The cracked distillate vapors leave the separator and are condensed in the usual type of box and coil condenser. The system runs under pressure. The vertical position of the tubes and the high velocity of the oil passing through them help to retard carbon deposition. This process presupposes high capacity per unit, and on this account, is said to produce excellent results. The average daily results per unit from the above process are reported as follows:

Throughput, 42 gal. barrels .....	400
Cracked distillate, barrels .....	200
Gasoline produced, barrels .....	120
Gasoline, per cent. of throughput .....	80
Gasoline, per cent. of distillate .....	60

Dubbs, U. S. patent 1123502, 1915, filed 1909, passes the oil through a continuous coil of 4 inch pipe which is exposed to the heating action of furnace gases. From the coil the liquid passes to a 10 ft. by 10 ft. vertical reaction chamber where the vapors are given off, passed through a dephlegmator and then to the condenser. Carbon deposition is retarded in the tubes of the furnace due to the high velocities. It is deposited and removed periodically from the expansion chamber. The distillate condensed is re-run for the gasoline content. The residuum is drawn continuously from the expansion chamber. The entire system runs under the pressure due to the vapors generated from the material undergoing cracking.

The results of the Dubbs Process on a Mid-Continent gas oil run and a fuel oil run are reported by the owners, The Universal Oil Products Co., as follows:

Charging Stock	Fuel Oil	Gas Oil
Hours Fire to Stream	5¾	6¾
Hours on Stream	56	235
Pressure (lbs.)	135	160
Baumé Gravity	24.2	35.7
Barrels Treated	1142	2591
Pressure Distillate Baumé Gravity	50.4	51.8
Total Barrels Produced	681	1831
Per cent. of Charging Stock	59.6	70.7
Residuum, Baumé Gravity	18.6	23.6
Total Barrels	466	748
Per cent. of Charging Stock	40.8	28.8
Coke (Tons)	5.8	3.5
Gasoline Produced (Barrels)	402	1091
Per cent. Gasoline of Charging Stock	35.2	42.1
Baumé Gravity of Gasoline	57.8	57.6
I. B. P.	114° F.	119° F.
E. P.	432° F.	426° F.

The Cross Process, U. S. patent 1255138, 1918, utilizes the principle of "synthetic crude." By this is meant a method by which the oil undergoing cracking is passed through an apparatus to change its characteristics without any separation or distillation taking place. The oil, now termed synthetic crude, is

then distilled by ordinary methods for the gasoline content which has been formed therein by the reaction in the apparatus. Cross advocates temperatures and pressures considerably higher than usually employed stating that the reaction is aided thereby.

The Cross apparatus consists of tubes arranged in series to which the heat is applied. The oil passing through the tubes enters a reaction chamber, where conversion into higher hydrocarbons takes place and where the carbon formed by the reaction is deposited. No distillation takes place in the reaction chamber or in any part of the apparatus. The "synthetic crude" is drawn continuously from the reaction chamber through a cooler for subsequent distillation.

A test run showed the following results: <sup>1</sup>

Oil processed, barrels .....	3030
Synthetic crude produced .....	2909
Gasoline produced .....	727
Per cent. gasoline .....	24
Fuel used, barrels .....	91
Fuel used, per cent. of throughput .....	3

The average cycle of operation is reported as one week with treatment of 4,500 barrels of oil. The above figure shows an average daily throughput per unit of 643 barrels. For the month of January, 1922, the commercial results from one Cross unit are reported as follows:

Gas oil used, barrels .....	15,427
Gasoline produced, barrels .....	4,186
Gasoline produced, per cent. ....	27.1
Fuel used, barrels .....	420
Fuel used, per cent. ....	2.7
Loss, per cent. ....	4
Average daily throughput, barrels .....	498
Average daily gasoline production, bbl. ....	135

The Emerson "Impact" system <sup>2</sup> employs the usual principle of pyrogenic decomposition and in addition atomizes the heated oil through two diametrically opposed orifices the jets impinging

<sup>1</sup> Bulletin Number 16 Kansas City Testing Laboratory.

<sup>2</sup> U. S. patents 1346797, 1346798, 1367806 and 1367807.

against each other from which feature the process derives its descriptive name. The advantage claimed for the impact feature is that due to the change of energy ionization takes place within the molecules thus producing a further chemical change. The commercial form of apparatus consists of a tube bank with headers and drum superimposed upon which is the chamber for the impact principle. The reflux from the chamber is returned to the still, the vapors passing on to the fractionating condensers.

A digest of the results of a test run on a 44.1 Baumé gravity kerosene distillate are:

Naphtha distillate, per cent. ....	89.11
Naphtha distillate, Baumé gravity .....	53.0

Upon redistillation the naphtha distillate yielded 65 per cent. of gasoline which corresponds to 57.92 per cent. conversion of the kerosene distillate. The specifications of the gasoline produced are Baumé gravity 55.6 degrees, initial boiling point 118° F. and end point 447° F. To produce such results the kerosene distillate was recycled which reduced the throughput of the still. The gasoline production per unit per day was estimated under the above conditions as 32.1 barrels.

Operating commercially upon gas oil this process is reported to have a daily throughput of 114 barrels per day with a gasoline production of 42.2 barrels corresponding to a yield of 37 per cent. of the charge.

R. Fleming, U. S. patents 1324766, 1325668, and 1394987, claims that the cracking reaction may be advantageously performed by the introduction of the oil to be cracked into the bottom of a column of heavier oil heated above the reaction temperature. Under present modifications a 10 by 30 foot still is set on end in a furnace so designed that only the vertical circumference of the still is subjected to heat. The heat is applied over almost the entire vertical surface. To attain the temperatures desired, pressures of 110 to 120 pounds are maintained. The pressure is relieved by a water cooled needle valve in combination with a jet condenser. The rapid reduction in volume



FIG. 82  
Fleming cracking still.

of the vapors results in condensation at or slightly below atmospheric pressure. The mixed vapors and water from the condensers are subsequently separated by gravity. The advantages claimed for the process are extreme simplicity with consequent low initial and maintenance costs. Fig. 82 shows the general arrangement of the process. Typical operating data averaged from several runs on Mid-Continent gas oil are as follows:

Charge 42 gallon barrels .....	322.6
Feed 42 gallon barrels .....	246.6
Total charge and feed .....	569.2
Gravity of charge and feed .....	34.14
Cracked distillate produced, barrels .....	266
Cracked distillate, per cent. ....	46
Cracked distillate, gravity .....	53.1
Gasoline (437 end point) in cracked distillate per cent. ....	75.96
Gasoline produced, barrels .....	203.65
Gasoline, per cent. of total charge and feed .....	35.8
Complete cycle hours .....	69.5
Throughput, daily average .....	196
Average gasoline production per unit per day .....	70.4

The reader has probably been impressed with the large variation in the percentage yield of gasoline as reported for the processes described. It should be borne in mind that this is largely due to variations in the time element. If a process is retarded the yield will increase and vice versa. The gasoline output per unit per day will however remain fairly constant. It should be noted, however, that carbon troubles may develop particularly with tube processes if the throughput is decreased. The combination of throughput and yield must therefore always be considered together.

The operations above reported are with one exception based on "once through" operation. The residuals from cracking contain a large portion of hydro-carbons that belong to the same group as the original charging stock. These may be removed by distillation and recycled through the apparatus with further gasoline yield. Practical commercial net yields of 55 to 60 per cent. of gasoline from gas oil are possible in this way. The intro-



duction of the recycled stock with the charge or feed reduces the capacity of the apparatus for fresh gas oil. For instance an apparatus capable of handling 200 barrels of stock per day "once through" with 35 per cent. yield could consume only 117 barrels of fresh gas oil daily if operated on the recycling principle for a maximum of 60 per cent. net yield. The production of gasoline per day would however be practically the same. To avoid confusion in calculations of this kind it would seem better to rate cracking stills on gasoline production per day.

With due regard to the patent situation and the financial returns a refiner considering the possibilities of a cracking process should give particular attention to the following points.

What are the working temperatures in the still and in the steel shells of the stills or tubes? The strength of steel at ordinary temperatures is well known. Also steel at cherry red temperatures and above is known to have lost most of its strength. Only recently have the results of tests been available which show the relation between ultimate strength and elastic limit and

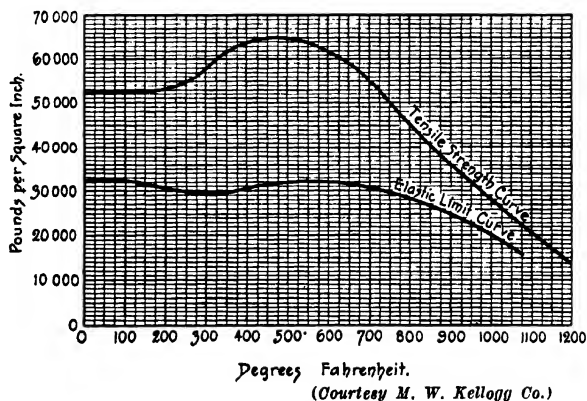


FIG. 83

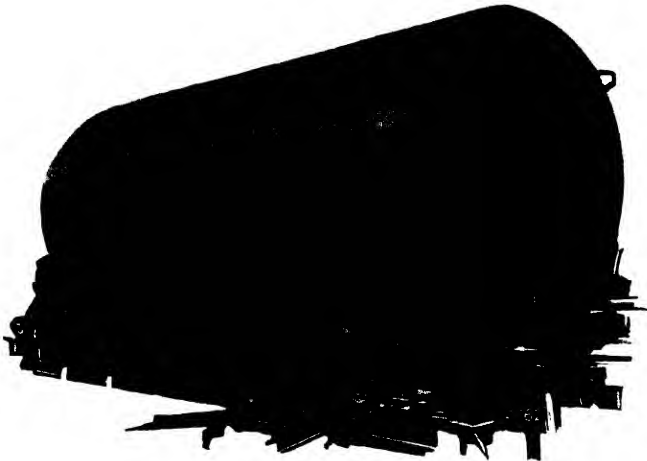
Effect of temperature upon steel.

the temperatures encountered in cracking apparatus. Fig. 83 shows this relation for a special steel used by one of the companies manufacturing large numbers of pressure vessels for this service. It should be noted that a reduction of fibre stress of from 25 to 35 per cent. should be allowed for in the design.

Riveted pressure stills should be built in accordance with the best boiler practice. Butt strap joints with drilled rivet holes are recommended. The rivets should be spaced to insure oil tight joints. Some companies electric weld the edges of plates after riveting to insure tightness.

On account of the trouble experienced in keeping riveted joints tight under the severe service of alternate heating and cooling, many companies prefer the forge welded still. Fig. 84 shows a forge welded still ready for shipment. An added advantage of the forge welded still is the elimination of the danger of a seam ripping under sudden increased pressure. Only stills made by actually forging the plates together at a white hot welding temperature with power hammers should be accepted. Autogenously welded vessels are not acceptable for pressure cracking service.

Another factor that must be taken into account in calculating



(Courtesy M. W. Kellogg Co.)

FIG. 84

Forge-welded high pressure still.

plate thicknesses is the liability of corrosion. This corrosion due to sulphur and other compounds in the oil is noticed particularly in the vapor space of the still. Examples of corrosion below the

oil level are extremely rare. The minimum and maximum rates of corrosion reported are 0.01 and 0.03 inches per year, the former for clean sweet gas oil and the latter for a Mexican product of high sulphur content. An additional allowance of metal should be made for this deterioration. The added costs of the slight extra original thickness is small when the increased life of the apparatus is considered.

The dephlegmating system should be of ample capacity not only to avoid excessive re-running, but also in relation to the effect on operation. An analysis of the successful processes shows that the amount condensed and returned or "cut back" to the still is from 8 to 10 times the amount allowed to pass on to the final condensers. The capacity of the cooling system used for dephlegmation may be easily checked by the usual methods.

To effect the above amount of distillation, allowing for a proper "cut back," approximately 3.0 to 3.25 square feet of heating surface are required to produce one gallon of cracked distillate through the final condensers, per hour.

In the case of tube stills, used in liquid phase cracking ease of cleaning and replacement are important. High tube velocities and vertical heating surfaces aid materially in preventing carbon deposition.

On account of the excessive wear and tear on apparatus, depreciation and maintenance are among the largest items in the cost of producing pressure-still gasoline. This is shown by the following analysis of operating costs of one well-known process. Depreciation is taken at 15 per cent. of the cost of the distillation plant and auxiliaries. The figures are percentages of total operating cost:

	Per cent.
Depreciation .....	41.7
Repairs .....	13.9
Fuel .....	23.2
Labor .....	14.1
Steam .....	4.2
Water .....	2.9
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	100.0

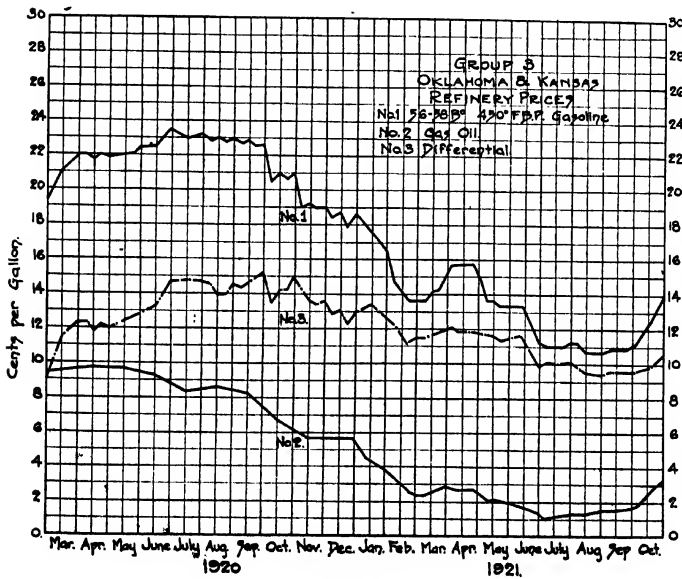
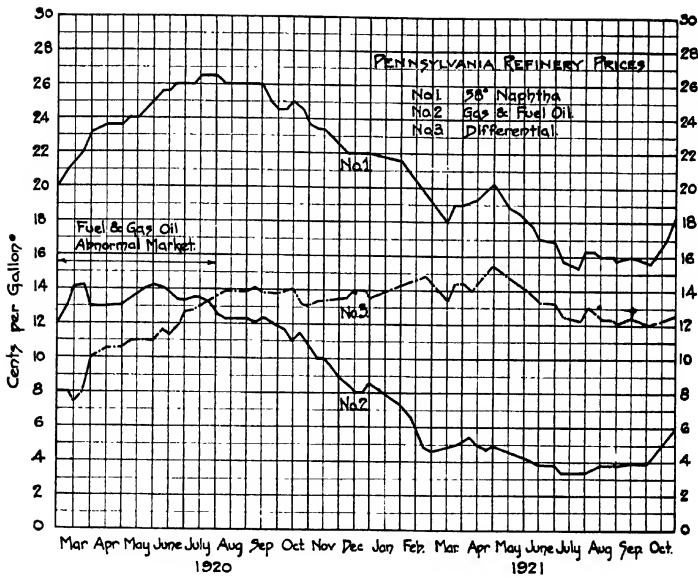


FIG. 85

Relation between prices of gas oil and gasoline.

These results show the importance of reducing depreciation and maintenance expense to a minimum. For this reason, plants should be designed from the standpoints of low first cost and reliability as well as that of good operating results. Better commercial returns are often attained by simple, reliable processes, than by others which show larger gasoline yields or lower fuel consumption, but which are expensive on a throughput-per-dollar basis, or involve excessive maintenance.

The point to be considered by the refiner in analyzing the return from cracking is not necessarily the market price of gasoline but rather the differential between gasoline and gas oil. This differential is quite constant, as shown by the curves for Pennsylvania and Mid-Continent refineries, Fig. 85. From March to July, 1920, there was an abnormal fuel oil market. With these months eliminated, the curves show a widely fluctuating gasoline market, but a rather constant differential.

Although not strictly cracking processes in the popular sense of the word, mention should be made of the decomposition of hydro-carbons by chemical means. It was early discovered when heated in the presence of aluminum and other metallic chlorides that heavy petroleum products were changed into products of lower molecular weights. Aluminum chloride has proved to be the most active of the reagents used. No entirely satisfactory explanation of the chemical reactions has been proposed. As in the case of pressure distillation, however, results are well known.

The McAfee process (various U. S. patents) is the best known of those in present day use. As practiced, the process operates on crude oil. Since the oil must be free from moisture before coming in contact with the aluminum chloride, it is customary to dehydrate it by a preliminary skimming distillation or, at least, to hot-settle the moisture therefrom. Anhydrous aluminum chloride in quantities of from 10 pounds to 25 pounds per barrel is then mixed with the oil in a still equipped with a stirring device. An adaptation of the Frasch desulphurizing or "sweetening" still has been used with success.

Boiling of the mixture usually takes place around 500° F. and is maintained between this temperature and 550° F. Since

the aluminum chloride vaporizes at these temperatures, it has been found necessary to provide reflux condensers to reduce the vapor temperature prior to admitting vapor to the coils of the final condenser. The reflux condensers are drum-shaped and so proportioned that the outlet temperature can be held under 350° F. This prevents the aluminum chloride from entering and choking up the condenser coils, and returns it to the still with the cut-back.

After a sufficient amount of distillation to convert the portions desired into light boiling fractions, the residual in the still remains suitable for the manufacture of high grade lubricants. This result is unattainable under pressure cracking methods. The residual is pumped off for further treatment. The aluminum chloride is left in the still with any coke which has formed in a granular mass. The reclamation and further use of the material follows.

It is claimed for this process that the quantity of gasoline produced may be varied by converting more or fewer of the heavier fractions. As usually practiced, it is customary to convert the less valuable gas oil portion and leave the heavier fractions for further manufacture into lubricating, fuel and road oils. The gasoline is said to be saturated, sweet and water-white hence the further treatment is limited to washing, or to alkali treatment and washing.

Recent patents by McAfee (U. S. 1326072 and 1326073) introduce the vapors from an ordinary pressure cracking still directly into another still containing a boiling mixture of oil and aluminum chloride, as described above. The yields of gasoline will come partly from the cracking still and partly from the aluminum chloride reaction. Both parts are said to be of good quality clean and saturated.

There are three features in aluminum chloride processes which delay their adoption, viz.,

- The high cost of anhydrous aluminum chloride,
- The cost of regeneration,
- The excessive oil loss involved.

The first two are chemical manufacturing problems worthy of investigation. The third loss running from 12 to 14 per cent. of the charge, is due to the formation of coke and the inclusion of oil with the aluminum chloride and the coke. This oil is difficult to recover when reclaiming the aluminum chloride. Further research and study on these points, if successful, will undoubtedly give the aluminum chloride processes much greater popularity.

## CHAPTER XI

### CHEMICAL TREATMENT

Object of treating various stocks—Methods—Agitators—  
Continuous treating—Various new systems.

Many refinery products must be purified by chemical treatment. In general, the objectionable bodies to be removed are the unsaturated hydrocarbons, sulphur compounds, and other minor impurities. Before discussing the plant requirements in detail, the treatment accorded these objectionable bodies will be considered.

Unsaturated hydrocarbons are often the cause of unstable gasoline which goes "off color" in storage. Nevertheless, they are now considered by many of our best authorities as among the most valuable constituents of gasoline for motor use. This is particularly true of the unsaturated olefine group. The presence of di-olefines is, however, objectionable, not so much on account of color, or even odor, but because of a tarry residue which is deposited after combustion in the motor cylinders. These bodies are also liable to cause trouble by depositing gummy matter in the carburetor. Odor is objectionable to the user, principally because of its unpleasantness. It is not necessarily an indication of poor results in the motor.<sup>1</sup>

E. W. Dean<sup>2</sup> summarizes the desirable properties of gasoline under the following headings:

1. The gasoline should not contain too large a percentage of highly volatile products, which tend to cause large evaporation losses and excessive danger in handling and storage, but should have enough volatile constituents to permit starting an engine under reasonably unfavorable conditions without preheating.

<sup>1</sup> Ellis and Meigs, "Gasoline and other Motor Fuels": G. Egloff, "Chemical Abstracts," 1917, 3425.

<sup>2</sup> Bureau of Mines, Technical Paper 214.



2. The gasoline should not contain any considerable percentages of heavy or non-volatile constituents, which, after delivery into the engine cylinders, cannot be completely atomized and burned.

3. The gasoline should not contain material that, after combustion, leaves a residue that collects in the motor.

4. The gasoline should be free from substances that attack metal either before or after combustion. Unremoved acid falls under this heading.

5. Neither the gasoline or its products of combustion should have a strong or markedly disagreeable odor, since this is objectionable to users of automobiles.

6. The gasoline should be free from non-combustible material, such as water and sediment.

Mr. Dean makes no reference to color, and the odor specification refers only to "strong or markedly disagreeable odor," with the statement that "this is objectionable to users." Nevertheless, present-day trade demands a water white and sweet smelling product; and unfortunately an appreciable portion of our available motor fuel is destroyed by treatments to satisfy such demand.

Color- and odor-imparting bodies are usually removed with sulphuric acid. The amount of acid required varies with the raw stock. Straight run Pennsylvania products can be cleaned up with as little as 1 lb. of acid per barrel, while some cracked products require from 5 to 6 lbs.

The use of strong acid in gasoline treatment, as previously discussed, often destroys many of the valuable constituents.<sup>1</sup>

After treating with acid, the sludge is settled out and the oil is washed, neutralized with a weak soda solution, settled and washed again; and after final settling is usually acceptable.

Sulphur compounds usually cause exceptionally disagreeable odors. Some of them are removable by the "doctor" treat-

<sup>1</sup> Ellis, U. S. Patent 1,318,061, observes that the action of the acid is often responsible for discolored products due to the formation of dye stuffs soluble in gasoline. His process covers the use of dilute sulphuric acid of from 40 to 70 per cent. strength. After the usual neutralizing and washing, the result is said to be a stable water-white gasoline. The weak acid will not destroy as many of the acceptable unsaturated bodies.

ment. The doctor solution is a mixture of caustic soda solution and litharge in the approximate proportions, 2 parts sodium



FIG. 86

Agitators of the Tiona Refining Company at Clarendon, Pa.

hydroxide, 16 parts water and 1 part litharge. The treatment generally follows the usual sulphuric acid process. After the solution has been in intimate contact with the oil, it is settled and drawn off. Flowers of sulphur are then added and the mixture agitated; and upon settling, the excess plumbite is deposited as lead sulphide. Washing with water completes the treatment.

Other sulphur compounds are harder to remove. The Frasch system of distillation with copper oxide has been largely used in such cases. Since very little crude containing these more ob-

jectionable compounds is now available, the problem is less acute today than formerly.<sup>1</sup>

It is often possible to eliminate gasoline treatment entirely, or at least to confine it to the heavier ends and to products from cracking processes. Opinions vary as to the advisability of treating the crude distillates or the closer re-run cuts. In the case of cracked products or those requiring heavy treatments, treating should be carried out prior to redistillation. The sweetening effect of the steam still operation is effective in removing any tarry matter formed in the oil after treatment. In fact, with pressure still distillates, a light treatment prior to re-running, without effort to obtain high color or odor standards, is said generally to yield better products upon redistillation than considerable work expended upon the products themselves.

Burning oils must be treated to remove the unsaturated bodies. When the oil is burned, these bodies are not completely oxidized and produce a smoky flame. Sulphur compounds are also objectionable and are usually the cause of carbonization upon the lamp wick. Although the procedure is much the same as with gasoline and naphthas, more acid is necessary and more time is required. The burning oils are treated until water-white or standard white. In this case, the color characteristic is of real value as an indication of the removal of the objectionable bodies.

Authorities differ with regard to the treatment of lubricants. Some claim that certain unsaturated bodies are liable to break down under high temperature and to release free carbon. Asphaltic hydrocarbons are regarded as of this class. These bodies are readily attacked by strong sulphuric acid and thus may be removed. Other authorities believe these naphthenes to possess good lubricating qualities and contend that the only reason for acid treatment is to improve color. It is beyond the scope of this chapter to go deeper into the matter. In any case, it is usual to give the lubricants a thorough treatment.

<sup>1</sup> Processes of interest in this connection are those of Snelling, U. S. Patent 1,215,732 (1917); Hall, British Patent 26,756 (1913); Robinson, U. S. Patent 910,584 (1909); Frasch, U. S. Patent 622,799 (1899).

The amount of acid varies according to reports from 20 lbs. of 66° B. acid per barrel for a high grade Pennsylvania pressed distillate to 60 lbs. for a heavy Texas product. Washing, neutralizing and washing follow the acid treatment.

Lubricants present some special treatment problems. After acid treatment, the oils are handled at a high temperature (150°–200° F.), necessitating steam coils and suitable insulation. The soda solutions are liable to emulsify, particularly if excess quantities are present. The washwater does not settle readily and the moisture usually has to be removed by an air blast, a procedure termed "blowing bright." The acid sludge, composed of the combination of acid and the asphaltic bodies, is excessive.<sup>1</sup> Its disposition is difficult.

Wax is treated to remove occasional foreign matter and impurities. A washing with hot caustic solution followed by hot water is generally sufficient. The batch is then blown dry with air.

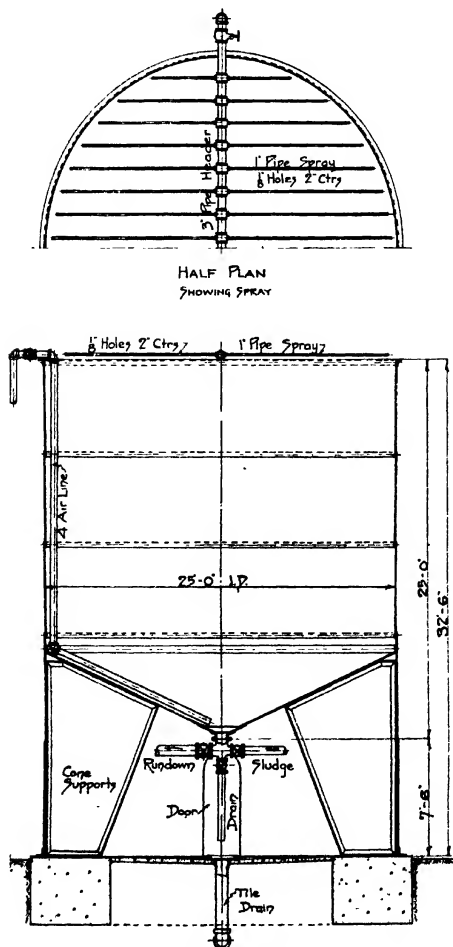
Many chapters, additional to the brief discussion, which the scope of this volume permits, could be written on the chemical treatment of petroleum products. The equipment required for this class of work will now be discussed.

Gasoline may be treated in the well-known agitator apparatus or by the more modern continuous equipment. A modern agitator is shown in Fig. 86. Fig. 87 shows a section of a thousand-barrel light oil agitator. It consists essentially of a cone bottom tank fitted with charging, draw-off, water and chemical piping.

Agitators range in capacity from 150 to 5,000 barrels. For many years the extension of the shell was designed to serve as the support. This construction necessitated gussets or trusses under the cone proper and was extremely heavy. Recent designs have eliminated the shell extensions and cone supports, resting the agitators by lugs on steel or concrete columns, as indicated by Fig. 88. If the columns are of steel, adequate fireproofing is necessary.

<sup>1</sup> See Chapter XXI\*

The pitch of the cone for light oils need not exceed 4 inches per foot from the horizontal. The sludge is not so viscous that it cannot be easily withdrawn with such a pitch.



CROSS SECTION  
FIG. 87

1,000-barrel agitator.

Early construction favored hemispherical globe roofs. Experience has shown, however, that this "gas bag" roof is a

source of danger. The accumulation of gas under the roof, along with the air from agitation, present ideal conditions for an explosion. A low globe roof is preferable and plenty of explosion hatches are advisable. Cases are on record where even a 10 per cent. relief area has not prevented the roof of a light oil agitator from being blown off by an explosion.



*(Courtesy Chicago Bridge and Iron Works.)*

FIG. 88

Agitators of the Atlantic Refining Company at Brunswick, Ga.

As a further safeguard against such accidents, the roof shown in Fig. 89 is favored by many refiners. In this type, from 55 to 60 per cent. of the roof area may furnish relief in case of explosion by the lifting of the two segments. After striking the kickback structure on the lantern, the two sections will fall

and cut off any ensuing fire. This construction is believed to have prevented many serious agitator fires.

At one time, mechanical agitation was used to prevent evaporation losses when treating, but few plants are so equipped today. An interesting modification of mechanical agitation is the use of large centrifugal pumps drawing from the tip of the cone and discharging into the top of the agitator. The circulation is said to result in a sufficiently intimate contact of oil and chemicals to produce good results.

The air blast is now in general use. The pressure required is low and need be only sufficient to overcome the static head of the oil. The volume should be ample, at least 200 to 250 cubic feet of free air per minute per 1,000 barrels of charging capacity. While still in universal use for the kerosene portions of light oils, the loss by evaporation in the case of gasoline is so serious as to condemn air agitation for this volatile product. Continuous treatment, later discussed, is thus largely supplanting agitators for gasolines and naphthas.

While strong sulphuric acid, above 60° B., is not particularly corrosive on steel, the washing with water results in the formation of a weak acid (below 60° B.) which is very destructive. Most light oil agitators are, therefore, lead lined. Some refinery constructors use no further support for the lead than to hang the lining from the top angle, dress it to the shell and bring it through the neck of the drawoff casting on the tip of the cone. Since the vibration due to agitation is liable to cause such a free lining to creep, buckle and ultimately crack, it is better practice to use lead straps to hold the lining in place. Fig. 170 shows the detail of a lead strap and its method of application. Experience indicates a maximum distance of about eight feet on the circumference for the spacing of lead straps.

Lead sheets weighing 8 lb. and 10 lb. per square foot are generally used on the vertical portion and cone of the shell respectively. Lead containing 6 per cent. antimony is a popular material. In this case, sheets one-half pound lighter are satisfactory. The antimony lead is said to give better service but is harder and, therefore, more difficult to apply.

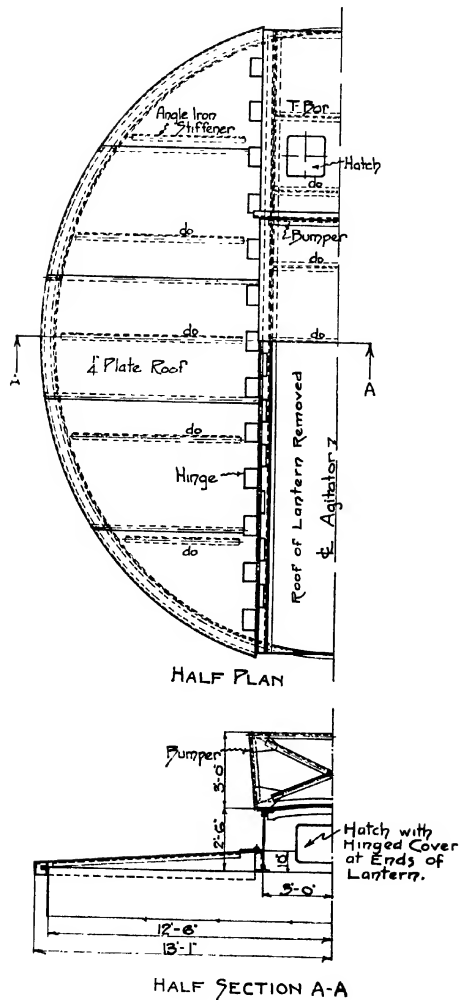


FIG. 89

Explosion type roof for light oil agitator.



With a tight lining, it is apparent that the expense of caulking the steel shell can be avoided. Lining leaks are difficult to locate. Some refiners recommend the omission of occasional rivets so that the location of a leak may be readily determined.

The following is a typical kerosene treatment in a 1,500 barrel agitator:

The agitator is charged and the necessary quantity of acid is added. After thorough agitation with air for 15 minutes, the batch is allowed to settle. It takes from one-half to two hours for the sludge to settle to the bottom. In order to remove traces of acid, water is sprayed down through the batch for 15 minutes and then drawn off. Soda solution, followed by more water, is then introduced through the top spray. This step requires from 15 to 20 minutes. Prior to drawing off the soda and water, the batch is again agitated with air for 15 or 20 minutes and allowed to settle. Care must be taken throughout the above procedure to prevent the temperature from rising above 75 or 80° F. In order to remove all of the soda, warmer water is required, and the batch is therefore washed with water at a temperature of 100° F. It requires from 45 minutes to 2 hours to effect this final warm wash, after which the stock is finished and drawn off. The time consumed from charge to charge is 6 or 7 hours. One batch per day can readily be obtained.

The continuous system of gasoline treatment is now generally conceded to be markedly superior to treatment in an agitator. Nearly all gasolines, excepting those containing unusually stable sulphur compounds, may be treated successfully by the continuous method. In the case of kerosenes its superiority is not so apparent, and general practice continues the customary agitator treatment for this class of products. The great advantage of the continuous system is the reduction of evaporation losses. In an agitator, a loss of from 1 to 2 per cent. from this source alone is often encountered; and this loss may be practically eliminated by using the closed continuous system. Furthermore, comparative tests have shown the continuous treater to require approximately 50 per cent. less acid and 25 per cent. less soda than the agitator.

Fundamentally, the system is a series of closed tanks, as shown in Fig. 90. The steps in the process are:

1. Preliminary settling,
2. Acid treatment,
3. Acid settling,
4. Washing,
5. Washing,
6. Settling,
7. Soda treatment,
8. Soda settling,
9. Washing,
10. Settling.

The gasoline enters the bottom of each tank and leaves at the top, passing through the chemicals and water as indicated.

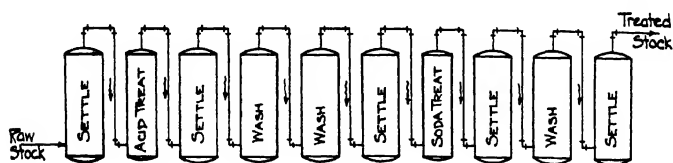


FIG. 90

Diagram of continuous system of gasoline treatment.

The original treaters had elaborate devices to circulate the chemicals from the bottom of the tanks to the top and spray them down by baffles or perforated pipes through the ascending gasoline current. Present systems, however, usually pump the gasoline through the acid and soda, which are quiescent in the lower parts of the successive cylinders. If more intimate contact proves necessary, sufficient circulation of the chemicals from bottom to top of their respective tanks is obtained by using small auxiliary pumps. From time to time sludge may be drawn from the two treating tanks, 2 and 7, and also from the following settlers, 3 and 8. Fresh chemicals are then added. The water is usually sprayed continuously into the tops of the wash tanks and withdrawn below. Some refiners find that they can

leave the wash tanks about one third full, drawing off and replenishing them intermittently.

The capacity of continuous treaters depends largely upon the character of the oil, which governs the time to be allowed for contact with the chemicals. For distillates of poor quality, a velocity through the soda and acid treating tanks of one foot per minute with a treatment period of 36 minutes is recommended. For distillates of good quality, a velocity of two feet per minute and a period of 18 minutes in the vessel will be satisfactory.

Similar figures will suffice for the wash tanks, but the velocity through the settlers should not exceed one foot per minute. The largest variation caused by stocks of different quality is in the time interval required in the settlers. Extreme limits of 18 minutes and one hour are reported.

The construction of this type of treater offers no difficulties. Tanks 3, 4 and 5 must be lead lined. Fig. 91 shows a small system designed for 750 to 1,000 gallons of combined Pennsylvania naphtha and pressure still naphtha per hour. In place of riveted tanks, forge-welded pressure tanks have been used. The high grade soft steel used for forge welded tanks shows a remarkable resistance to corrosion. Such tanks may be used without lining. In riveted tanks, the hot rivet oxidizes slightly before driving. This small film of oxidized metal is readily attacked by both acid and caustic and appears to be the principal cause of failure.

Lubricating oil agitators, while similar to those for the light oils, have some peculiar characteristics worthy of mention. In most of the large refineries, the acid treatment is conducted in one agitator, after which the stocks are transferred to "wash" agitators or finishing agitators for final treatment. This transfer is made to facilitate neutralizing. Long delays may be encountered in overcoming emulsions. The removal of moisture may also be prolonged. If all steps were performed in the acid agitator, it might be tied up for days. By having three or four wash agitators for each treating agitator, the latter may

be kept in continuous service. In this case, the lead lining for the acid unit may be omitted. The cone or drawoff casting should be of ample size. The acid sludge from lubricating oils is very thick and viscous and no restrictions of opening should be allowed. An outlet diameter of from 12 inches to 18 inches is recommended.

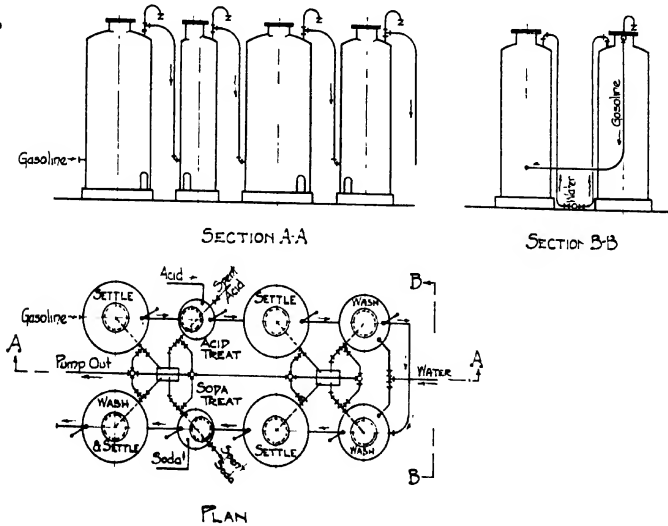
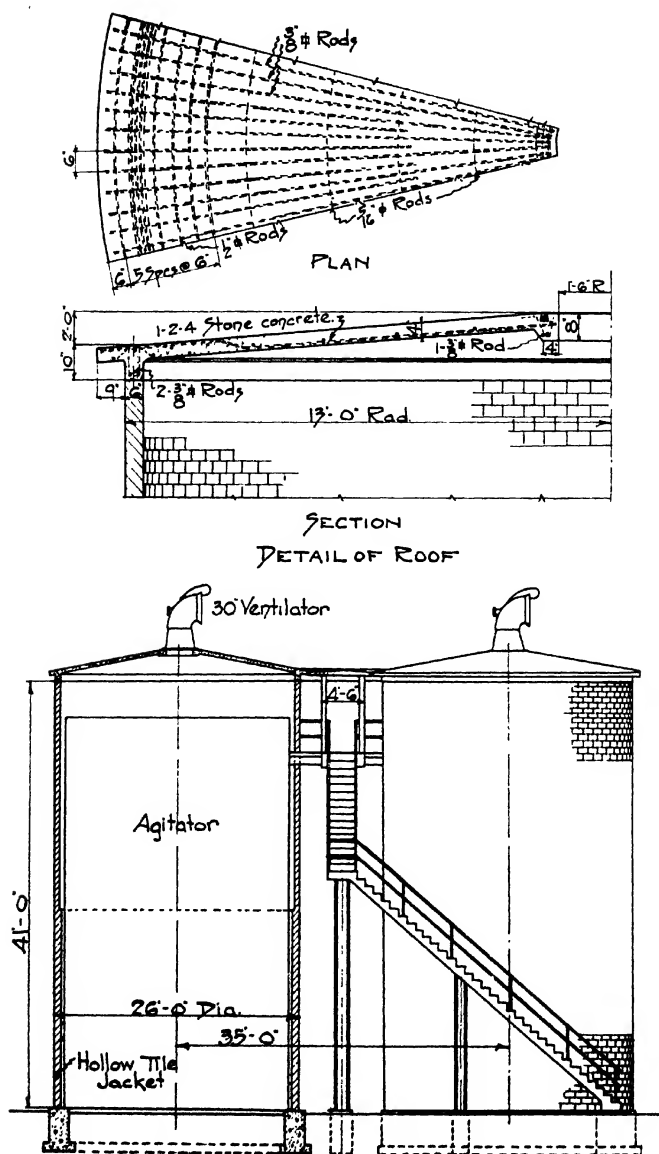


FIG. 91

Small continuous treater for gasoline.

Lubricating agitators are not usually constructed in capacities exceeding 2,500 barrels. Sizes of from 500 to 1,500 barrels are common. The yields of these stocks are smaller than the yields of light oils. Moreover, the process is more intricate and the batches are more often spoiled. If excessively large batches have to be reprocessed they overload the re-run stills and other facilities.

In order to avoid the possibility of sludge deposits the pitch of the cones should be not less than 45°. Since there is less fire risk in handling lubricating oil, medium depth steel globe roofs are satisfactory for the acid agitators. Moisture condensation



HALF SECTION &amp; ELEVATION

FIG. 92

on the under side of the roofs of wash agitators is objectionable and often serious. Some refiners overcome this difficulty by building the agitators without roofs and placing them in a building. Concrete roofs, independent of the wash agitators, and supported upon the tile insulating jackets, have also proved satisfactory. Fig. 92 shows this construction. On account of the possible presence of weak acid, the wash agitators require lead linings.

Lubricating oil treating is generally carried on at temperatures of from 150° to 200° F. The shells should therefore be insulated to insure economy, speed and control. The insulating jacket is usually built of hollow tile or hollow brick, and in order to avoid cracking due to vibration should not touch the agitator shell. From 4 inches to 6 inches of air space between shell and jacket is usual. Jacketed treating and wash agitators are shown in Fig. 93.

An outline of the process on a red paraffine oil from Texas crude will illustrate the steps taken.

After charging, from 40 to 60 lbs. of acid of 98 per cent. strength are introduced and the batch is blown for 15 minutes. Water is added sparingly, sufficient to coagulate the acid. Settling requires one-half to one hour and the sludge is then withdrawn. The batch is now transferred to a wash agitator. It should be noted that only four or five hours have been consumed in this part of the cycle and that the acid agitator is now ready for another batch.

Soda solution is now added and air agitation applied. On account of the liability of emulsion, care must be taken to avoid any excess in introducing the soda. The batch is heated to 180° or 200° F. and allowed to settle for eight or ten hours. By means of open sprays in the cone, steam is introduced for two or three hours in order to dissolve any further traces of soda, and the batch is again settled for three or four hours. The resulting sludge is drawn off and, while maintaining a temperature of 175° to 180° F. by means of the closed steam coils, under the cone and between the jacket and shell, the batch is "blown

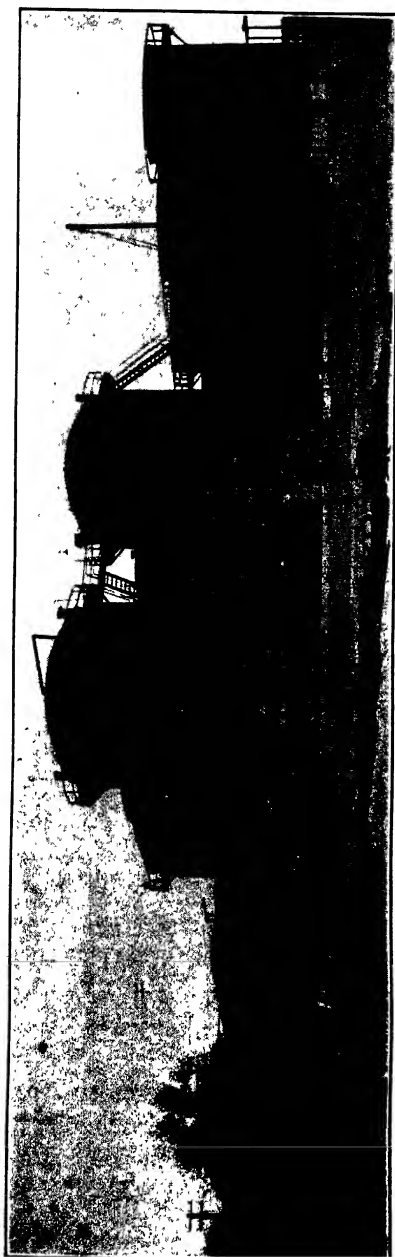


FIG. 93

Lubricating oil agitators of the Midwest Refining Company at Casper, Wyoming.

right" (moisture removed) with the air blast. The time required by this operation depends upon the moisture content, atmospheric conditions and temperature. From two hours to a day may be necessary. The full cycle requires from 18 to 36 hours. For such stocks, from four to six wash agitators are necessary for each acid agitator, depending upon the number of hours of acid treatment performed per day. Some oils, such as Pennsylvania neutrals, do not offer as much difficulty in finishing and three or four wash agitators are sufficient.

The chemical treatment of petroleum products offers a wide field for further research. The acid treatment of lubricants is particularly unsatisfactory. In this process, asphaltic bodies are formed similar in composition to those it is desired to remove. The expense for chemicals, equipment and labor is high, and the loss of oil during treatment adds further to the cost.

One or two of the processes developed toward the solution of this problem are described to illustrate the trend away from present practice.

Silica gel, a patented product of water glass treated with certain acids, has recently been introduced in the oil industry. Tests show this material to be particularly active in the removal of sulphur. Success is reported on low grade gasolines which heretofore have entailed excessive treating costs. This product is also believed to be applicable for the reduction of color in lubricants, eliminating the losses caused by the present acid method. A plant with a daily capacity of 1,000 barrels of low grade gasoline per 24-hour day is shown in Figs. 94 and 95. The oil passes in series through the six units, counter-current to the silica gel. Each unit consists of a small agitating tank in which oil and reagent are mixed, and of a thickening tank where the silica gel is settled out and pumped to the next higher agitator, the oil overflowing to the successively lower agitators. The silica gel is pumped from the last unit to a washing apparatus, and is then filtered and reclaimed as the original white powder in a special apparatus termed the *activator*. The plant shown will circulate 50 lbs. of the silica gel per minute. The oil



treatment capacity varies with the character of the oil. Two men are required on each shift. An average of 35 horse power is required.

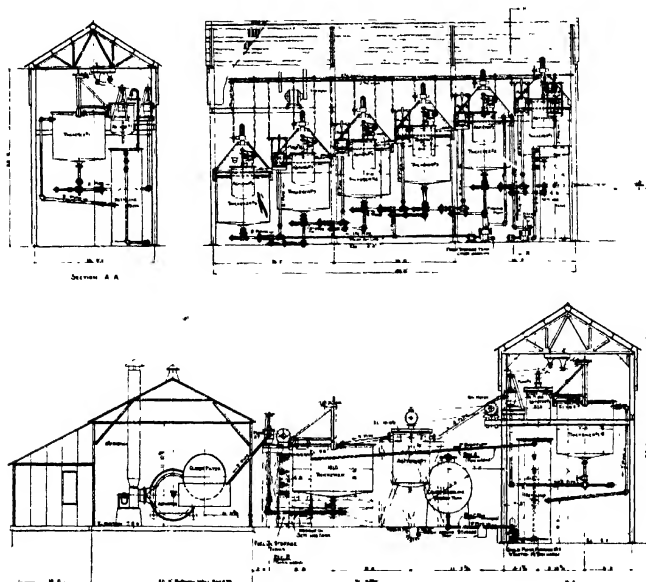


FIG. 94

Plant for naphtha treatment with silica-gel.

T. T. Gray<sup>1</sup> purifies petroleum products by passing them in the *vapor stage* through porous material of high absorbing power. Fullers' earth fulfill the requirements. The advantages claimed are the possibility of combining treatment with distillation, the reduction of losses due to acid treatment, and an increased yield of light products. The last advantage is due to combination of the hydrogen of the fixed gases with the unsaturated portions of the vapors. The Hall process (various British and French patents) is similar.

R. Fleming<sup>2</sup> introduces chemicals into the water or other

<sup>1</sup> U. S. Patent 1340889.

<sup>2</sup> U. S. Patent 1825668.

condensing medium of a form of barometric condenser adapted to still distillates. This method treats in both the vapor and the liquid stage, with thorough agitation by the water.



FIG. 95

Silica-gel treating plant of the Massachusetts Oil Refining Co. at East Braintree.

Numerous other methods have been proposed and tested. Present widespread interest will doubtless produce important changes in the near future.

## CHAPTER XII

### WAX PLANTS

Chillers—Refrigeration—Filter presses—Wax sweating—Oven design—Wax filtering and treating—Packing—Example of equipment calculations—Notes on building features.

The wax-bearing distillate from the crude is the basis for the manufacture of paraffine wax and the valuable neutral lubricating oils discussed in previous chapters. The removal of the wax, with its subsequent treatment, is carried on in *wax plants*. The wax distillate from the crude distillation is usually unfit for direct introduction to the wax plant. This is because the wax content is in an amorphous rather than a crystalline state. In this condition, it would gum up the wax presses and otherwise give trouble. It is found that by re-running the crude distillate



FIG. 96

Wax press house. Sinclair Refining Company, East Chicago, Ind.

in fire stills and curtailing the use of open steam sufficiently to allow the temperatures in the still to rise slightly above the cracking or decomposing point, the contained wax is altered to crystalline form.

The first step in the removal of the wax is to chill the wax distillate. The chilling temperature is a few degrees below the desired cold test of the neutral oil. Obviously, if the distillate is chilled to a certain temperature, and all crystalline wax then removed therefrom, the pressed oil, or oil from which the wax is removed, will no longer congeal or "chill" upon cooling, until the temperature drops below that at which the wax removal was accomplished. It is here, therefore, that the cold tests of many of our lubricating stocks are controlled.

In the United States, two types of chilling machine are used. The double pipe "chiller," shown in Fig. 97, is very popular. This machine consists of a number of 6 inch pipes in series, each jacketed by an outer 8 inch pipe. Inside of the 6 inch pipe is a screw conveyor driven by chain sprockets on an extension of the shaft at one end. This conveyor is necessary to force the congealed wax along with the oil. The cooling medium is circulated between the two pipes.

The capacity of chillers depends upon the initial temperature of the distillate. For ordinary conditions, one section of double

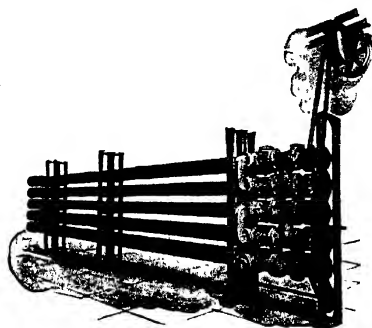


FIG. 97

Carbondale double pipe chiller.

pipe chiller will reduce the temperature of 30 barrels of distillate from 90° to 15° F. in 24 hours.

Double pipe chillers may be assembled in any number of sections up to twelve. Less than four sections per chiller are,

however, rarely used, since one small press would require at least this number. The exchanging surface per section of the Carbondale machine, Fig. 97, is 53 square feet. The rate of heat transfer between the oil and the cooling medium for this type of machine is  $\rho = 4$  to 5 B.t.u.<sup>1</sup> At this rate, one section will chill twenty-five barrels of distillate from 90° to 15° F. per 24 hours. This figure will allow for the "foots oil" recirculated.

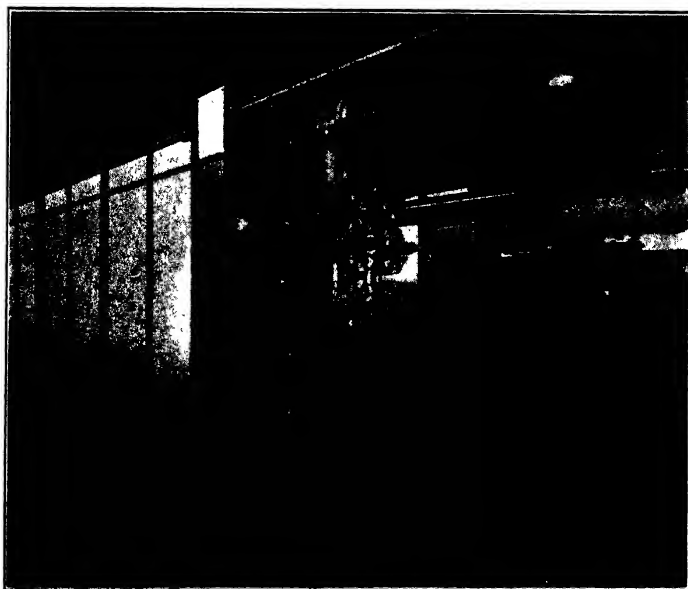


FIG. 98

Double pipe chillers showing insulation.

Chillers should be carefully insulated. Room insulation in this case is not so efficient as insulating the machine itself. An inexpensive and efficient method is to build a box of matched lumber enclosing all but the end fittings of the machine. This box should then be filled with ground cork. Fig. 98 shows a system using light sheet metal instead of wood.

<sup>1</sup> $\rho$  = heat transferred per square foot per 1° F. of mean temperature difference between the two mediums per hour.

In discussing chillers it is well to consider the power required to drive the screw conveyors. The drive is through a worm gear which greatly reduces the speed. Under normal conditions, individual motors of 3 H.P. will be satisfactory but 5 H.P. motors are customary to allow some leeway. Often, however, the pressure will mount and the load will exceed 5 H.P. with consequent blowing of fuses and possible "freezing" of the chiller before a new start can be made. For this reason, the writer favors the group drive for chillers. Five or less on a shaft are satisfactory. If a 25 H.P. motor is arranged to drive five machines in this manner and the load goes up on one or two machines, there is plenty of reserve power available. It is extremely unlikely that all five will give trouble at once. The group drive has the added advantage of lower first cost.

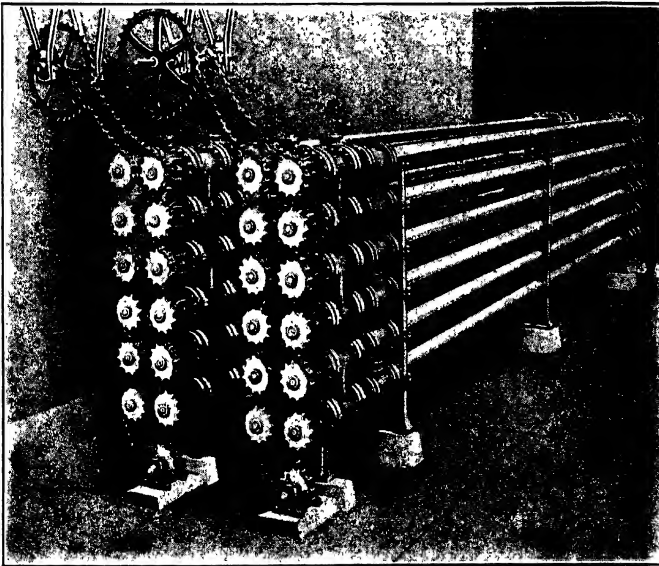


FIG. 99

Fahl double pipe chiller.

The Fahl chiller, Fig. 99, is another type of double pipe machine. The advantages claimed for it are compactness and

the elimination of abrupt changes in the direction of the oil current. This machine is also self-supporting.

Fig. 100 illustrates the Gray double shell type chiller. It resembles a gigantic ice cream freezer with power driven pad-

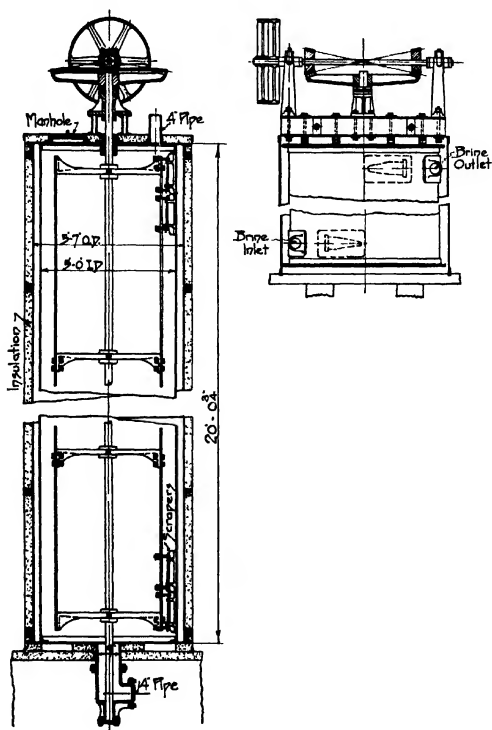


FIG. 100

Gray shell type chilling machine.

dles so arranged that when revolved the resistance of the oil forces the blades firmly against the shell. Hence the deposition of chilled paraffine on the shell is avoided, and the insulating effect of such a deposition overcome. The cooling medium (brine) is circulated between the two shells, the transfer of heat from the oil to the brine being through the inner shell. The

manufacturers of this apparatus recommend it for all temperatures down to 15° Fahrenheit. Below 15° the chilled paraffine wax has a tendency to adhere to the paddles, which increases

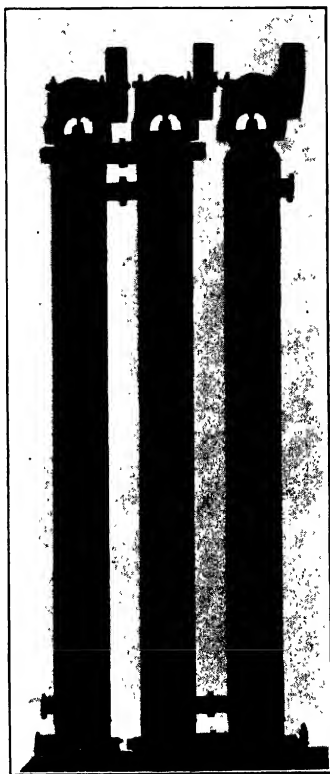


FIG. 101

Twenty-inch Gray chilling machine for low cold test oils.

the resistance and power requirement. Favorable features of the machine are its simplicity and large capacity per square foot of floor space. One Gray chiller is rated at 400 barrels (42 gal.) from 90° to 18° F. per day.

A new type of Gray chiller which embodies the above features but which may be operated at lower temperatures is il-





lustrated by Fig. 101. The vertical shells, while smaller than those described in the preceding paragraph, are similar in general design.

The absorption type of refrigerating system shown in Figs. 102 and 103, is in almost universal use for this kind of service at the present time. This system runs on exhaust steam at 3 lb. pressure or above. With the exception of the pumps, there are no moving parts, and the apparatus is very reliable. Refrigerating machines are rated on their ice making capacity in net tons per day. For ordinary wax plant design without unusual requirements such as the extra capacity for producing special stocks of extremely low cold tests, one-eighth of a ton refrigerating capacity is sufficient per barrel of wax distillate throughput per day.

Approximately 30 pounds of exhaust steam at from 3 lbs. to 15 lbs. pressure are required per ton of refrigeration per hour. The water consumption should also be considered. Four gallons per minute per ton of refrigeration should be allowed. The steam pressure on the generator will depend on the water temperature. Three pounds for water at 60° F. and 15 pounds for water at 75° F. represent the two extremes usually encountered in practice. Intermediate values may be interpolated.

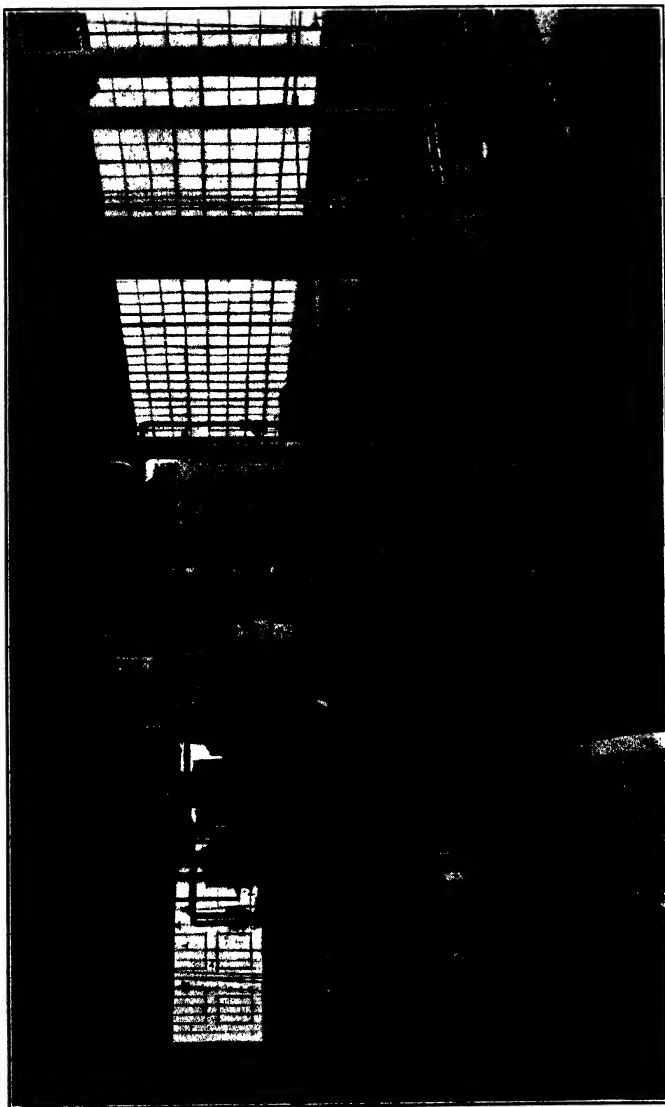
A short discussion of the calculations involved in refrigeration practice is here offered.

The unit of refrigeration is the heat required to melt one ton (2,000 lbs.) of ice, or, conversely, the quantity of heat which must be abstracted in order to freeze one ton of water. In practice, this quantity is taken at 288,000 B.t.u. A 1-ton refrigerating machine has the capacity for one ton of refrigeration per 24 hours.

The amount of refrigeration required to chill a substance from one temperature to another is expressed by the following formula:

$$T = \frac{WS (t_1 - t_2)}{288,000}.$$

$T$  = Refrigeration, tons.



(Courtesy Carbondale Machine Co.)

FIG. 103

Installation of six 100-ton absorption machines. Sinclair Refining Co., East Chicago, Ind.

$W$  = weight of substance, lbs.

$S$  = specific heat of substance.

$t_1$  = initial temperature.

$t_2$  = final temperature.

If  $W$  denotes lbs. *per day*,  $T$  is the rated tonnage of the machine. If  $W$  = lbs. per  $h$  hours, the weight of substance chilled per day is  $24 W/h$  and the rated tonnage of the machine is

$$\frac{24 T}{h} = \frac{WS (t_1 - t_2)}{12,000h}$$

One *gallon degree* is the heat required to change the temperature of one gallon of brine  $1^\circ$  F. per minute. In B.t.u., this quantity may be expressed as  $8.35 gs$ , where  $g$  = specific gravity of the brine and  $s$  = specific heat. Brine tables are available giving Baumé readings and specific gravities along with the specific heat and per cent. of salt or calcium chloride. The *gallon degrees* per ton of refrigeration is given by the formula:

$$G_t = \frac{34,491}{gs}$$

Knowing the quantity of brine circulated per minute and the drop in temperature through the brine cooler, the refrigeration rate per day is given by the formula:

$$\begin{aligned} \text{Tonnage rating} &= \frac{1440 V(t_1 - t_2)}{G_t} \\ &= 0.042 gsV(t_1 - t_2) \end{aligned}$$

$V$  = quantity of brine, gal. per min.

Where good water is obtainable, double pipe absorbers, rectifiers and condensers are recommended. Besides giving high efficiency, they may be placed under cover where they will receive attention. On the other hand, if there are scale forming ingredients in the water, a shell and tube absorber with atmospheric rectifiers and condensers placed on the roof is considered better practice. Shell and tube brine coolers are most commonly used.

Calcium chloride brine is usually employed for the chilling medium. The usual brine temperature is  $0^{\circ}$  F. Centrifugal or triplex brine pumps, power driven, are recommended. After passing through the oil chillers, the brine should return to a well-insulated brine tank, from which it is again pumped through the brine coolers and to the chillers in a closed circuit. Efficient flow meters and thermometers on the brine system will permit a constant check to be kept on the refrigeration. Where oils of extremely low cold test are desired, the ammonia from the absorption machine condensers may be expanded directly into a double pipe chiller. This direct chilling of the oil replaces the chilling of the brine in the brine cooler.

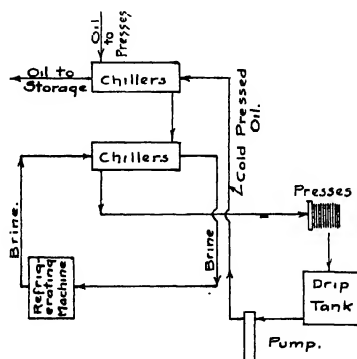


DIAGRAM ~ USE OF  
PRESSED OIL IN CHILLERS

FIG. 104

Since wax distillate has a high cold test, or in other words, chills rapidly at moderate temperatures, it has to be kept around  $90^{\circ}$  F. to be handled successfully with pumps. At this temperature, a considerable heat may be removed by water alone, and sometimes a chiller of the Gray type is reserved for this use. Again the pressed oil returning from the presses is, in the case of a single pressing, around  $16^{\circ}$  to  $18^{\circ}$  F. This oil is usually en route to distillation or treating apparatus and hence may well absorb heat from the wax distillate on the way to the presses.

A chiller of either type may be used for this purpose. Both of these steps will reduce the amount of refrigeration. Fig. 104 shows a chilling system using both the pressed oil and brine.

After chilling, the wax distillate is pumped through a filter press, Figs. 105, 106 and 111. The filter press consists of a series

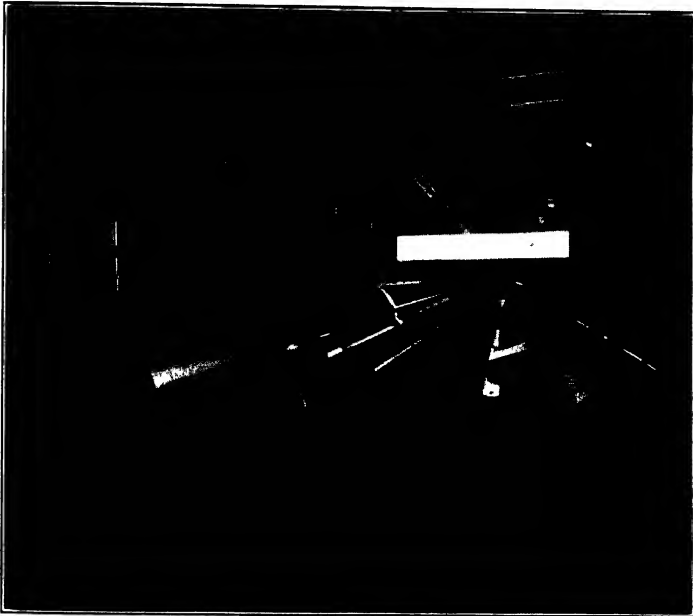


FIG. 105

Interior of press room.

of steel plates with perforated plates riveted thereto. In the center of each plate is a circular opening. A 12-ounce canvas blanket is drawn through this opening so as to lie against both sides of the perforated plates and is secured around the circumference of the assembly. Fig. 107 shows, in detail, a plate made up ready for the press. Spacing rings of two types are used between adjacent plates. Fig. 107 shows the separate type of spacing ring. The rings are  $\frac{1}{2}$  inch in thickness and are placed

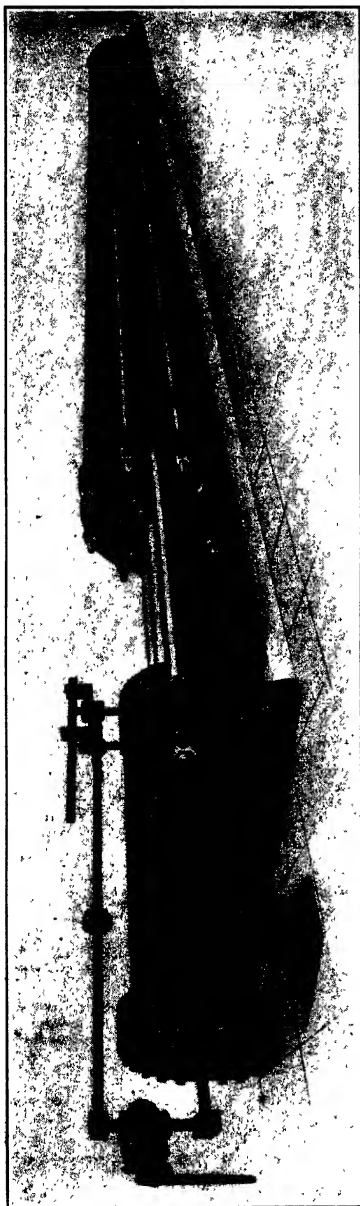


FIG. 106  
Moore filter press.

on the frame between each two press plates. Some companies prefer to have the rings attached to the press plates themselves. Fig. 108 is an assembly of this kind. The advantage is said to be in the reduction of the time required for dumping the press due to the fact that both ring and plate are moved by one operation. Contrary arguments discount the time saving element and hold that the "cake" will fall more freely with separate rings. The wear on the canvas blankets is more severe with the attached rings, and the first cost and repair expense are greater. For these reasons most companies favor the separate type of ring. The diameter of plates is usually made 27 inches or 48 inches, the latter being the more common in present use.

The capacity of filter press plates depends on the amount of wax present in the wax distillate. For a high wax content of 20 per cent., two 48 inch plates should be allowed for each barrel of wax distillate pressed per day. For a wax content of 10 per cent., one 48 inch plate per barrel will suffice. These figures allow sufficient leeway to take care of the foots oil later extracted from the wax and returned for pressing.

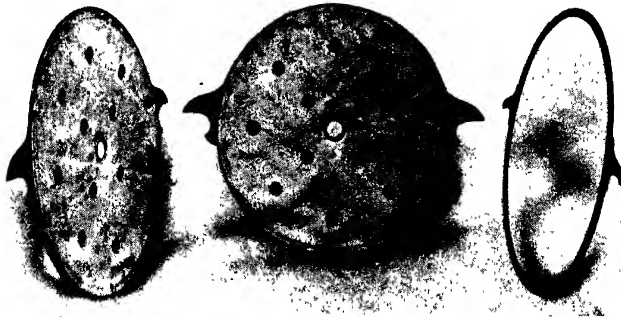


FIG. 107

Filter press plate.

The press plates are hung by the lugs from the side rods of the press frame. By using inverted lugs on every third



fourth plate the tendency of the press to buckle under pressure, forcing the plates near the center off the side rods, is overcome. Press frames are manufactured to accommodate any number of plates up to 500. When new, ten plates will occupy one foot of space between the platens. After some use, a few more may be added. As usually furnished, the plate space is from 30 to 40 feet. In this connection it should be noted that the larger presses will require more time to fill up and hence afford fewer cycles in a given period. Since it is more economical in investment to install four 500 plate presses than five 400 plate presses, the larger presses are recommended. Sufficient presses should be installed to provide one which is always ready for filtering and to take care of special stocks if such are manufactured.

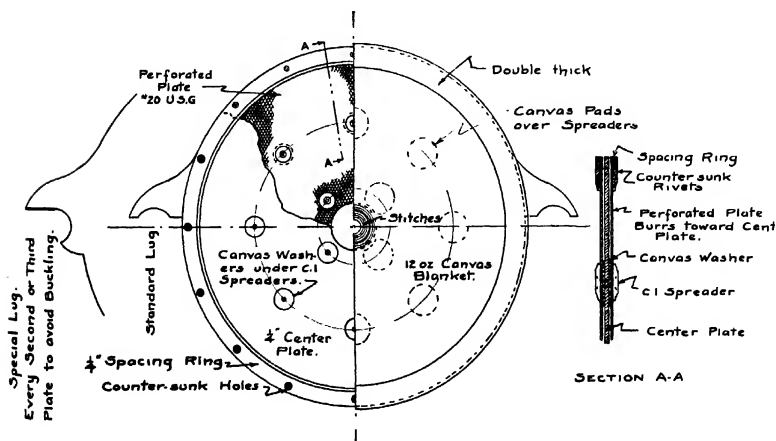


FIG. 108

Filter press plate assembled. Spacing rings attached.

After the plates are on the frame they are pressed together by the hydraulic ram, and the tension bolts are drawn tight. The press is then ready for filtering. The cold wax distillate from the chillers is forced through the annular opening formed though the center by the openings in the closely packed plates.

The course of the oil through the plates is shown in Fig. 109. The crystalline wax is retained between the canvas blanket. As this wax space gradually fills up, the pressure is allowed to mount to the practical limit, usually about 350 pounds per square inch, and the press is then ready for dumping.

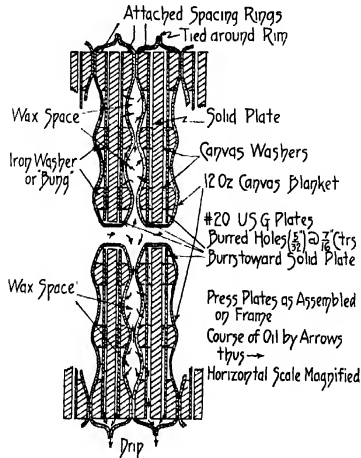


FIG. 109

Diagram showing course of oil through filter press blankets.

ment where there is more than one press is to place a relief valve on the line so that the wax distillate will automatically pass to the next press. While the wax is accumulating, the oil is dripping into a trough and being conveyed to the "drip" tanks, usually arranged so that each press has its own receptacle. Fig. 110 is a cross section of a 48 inch press showing the pressed oil trough in position.

To dump the press, the trough is rolled to one side by a lever mechanism, thus uncovering the wax conveyor directly beneath. The nuts or keys on the tension rods are then removed and the ram is reversed, moving the front platen back. Two men, one on either side of the press, slide the plates one after the other through the space made by drawing back the platen, and re-

move the wax cake from the blankets with spuds, the broken cake falling on the spiral conveyor which carries it to the wax "dump" tank. This tank is usually at the opposite end of the press from the drip tank for pressed oil. The wax is melted by steam coils in the dump tank and may then be pumped to storage.

The wax as taken from the presses is yellow, soft and crumbly, and contains a large amount of oil. It is called "slack



FIG. 110

Section of Kellogg-Gray filter press.

wax," and is now ready for further treatment to yield the various grades of commercial paraffine wax.

The building housing the refrigerating, chilling and pressing apparatus and auxiliaries should receive special attention.

The usual arrangement is shown in Fig. 112. Future extensions may be easily added. One modification of this arrangement places the chillers on a second floor directly over the presses. The oil outlets of the chillers should, of course, be

above the inlet to the presses. A pipe gallery, two stories in height, between the refrigerating room and the two story press and chiller section will be of service for the concentration of the piping between the two sets of apparatus. Fig. 113 illustrates this design. Buildings constructed of reinforced concrete, or of brick and steel with reinforced concrete floors, are recommended. The press rooms should be thoroughly insulated. One system uses two layers of 1 inch cork boards, breaking joints between layers. Nailing strips to receive this insulation should be left in walls and ceilings. Wire mesh and Portland cement plaster are applied over the boards. Sil-O-Cel brick for press room walls and partitions has also been used with success. These bricks have considerable structural strength and may be laid up in a partition 8 inches thick in the ordinary way. Plastering over wire mesh applied to the brick is necessary to lend sufficient stiffness to the wall. All press room doors should be of the "refrigerating" type, as used in cold storage work. Presses should be placed with the ram end toward an outside wall and, if possible, with a door opposite each press to facilitate the removal of the ram.

Steam pumps are to be recommended for wax plant service. The absorption refrigerating system and the heating of the tanks will utilize all the exhaust

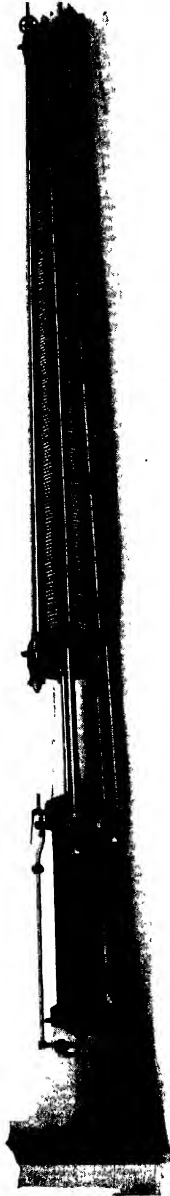


FIG. 111  
Kellogg-Gray filter press.

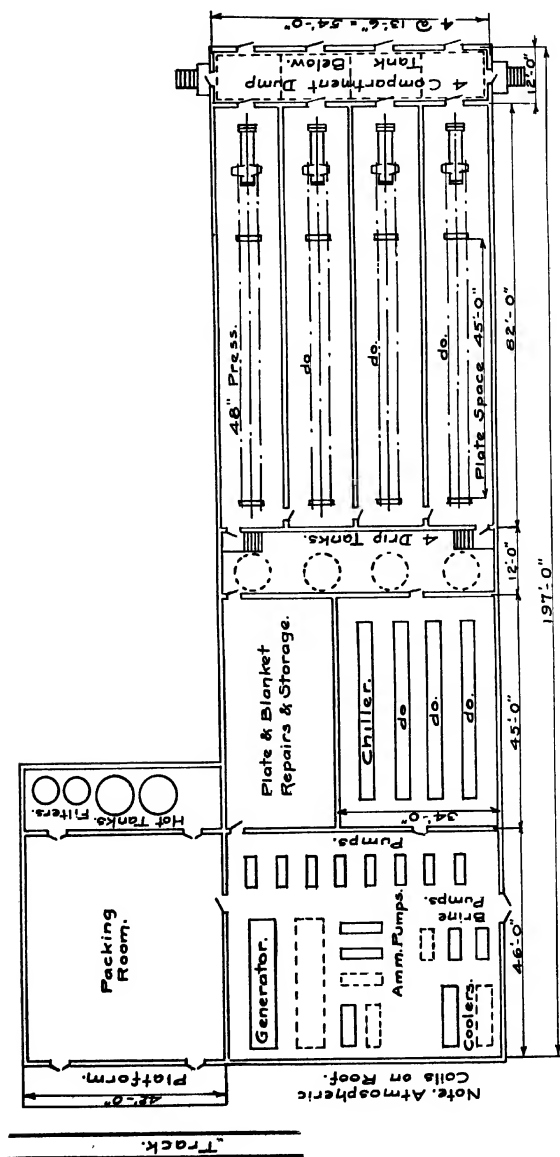


FIG. 112

General arrangement of wax plant.

steam. Since the exhaust steam requirements minimize the effect of high steam consumption, full advantage may be taken of the low first cost and reliability of steam pumps. Power pumps, engine driven, have proven economical, but in this case the power load is not large enough to furnish sufficient exhaust steam.

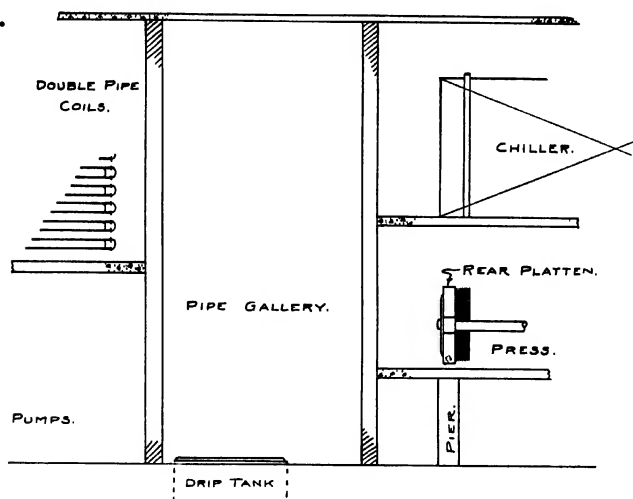


FIG. 113

Section through chiller and press rooms showing pipe gallery.

In the writer's opinion, all principal operations, including packing and shipping, should be housed in one building. Such an arrangement results in short pipe lines, low installation costs, and efficient management. The building shown in Fig. 112 houses all the steps of wax manufacture except sweating and treating. Some refiners prefer to have a separate building in which to filter, barrel and mould their wax.

Every precaution should be taken to conserve refrigeration. All brine pipes and cold oil lines should be insulated with best quality cork covering; and the brine coolers, absorber and generator should be properly lagged. These important points are often neglected.

As before stated, the wax contains a large amount of oil. This oil is removed by chilling the wax to a solid mass and then gradually raising the temperature. This process is based on the theory that, in the solid state, the wax crystals still have innumerable interstices and voids in which the oil is contained. As the temperature is gradually raised, the resultant expansion opens these cells so that the entrained oil may drain away. The process is called "sweating."

The apparatus used for this purpose usually consists of a series of shallow steel pans set in a bank several units high and enclosed in a room of good insulating properties. Installations vary as to size and details.

The pans in use by some of the older and smaller refineries are 8 by 20 feet in plan, and about 8 inches deep at the ends, sloping to a depth of 14 inches at the center. They are usually assembled in stacks, eight high, and with one or two stacks in a room or "oven." A rack made of light angle or tee iron is laid in the pan and carefully levelled. A galvanized iron wire mesh of 1 inch squares is then stretched across the rack and over this a brass wire cloth of 50 meshes per inch is securely fastened. A coil for cooling the wax is laid over this screen. Water is turned into the pans to a depth sufficient to just cover the screen, and the hot wax is then pumped in to a depth of 5 or 6 inches. This is about the maximum possible cake thickness if there is to be a uniform temperature throughout the cake. By pumping cold water through the coils, the wax is chilled below its melting point, and becomes a solid cake. The oven is then tightly closed, the water withdrawn from the pans, and by the use of steam coils along the walls the temperature is raised. The oil sweats out of the wax, drains through the screens, and by outlets at the low center of the pans, is led to storage. This oil is known as "foots oil." Two cuts are usually made, the first being straight foots oil, and the second a mixture of oil and wax in about the same proportion as that of slack on the pans. The second cut is usually introduced directly into slack wax and re-sweated. The process is continued at a certain temperature until

the oil is thoroughly sweated out. The remaining wax is known as "scale wax." This remaining solid wax will have a melting point approximately at the temperature at which "sweated," since all the portion melting at that temperature is removed by the process and is carried away by the foots oil. It is here, therefore, that the melting points of the waxes are controlled. The scale remaining on the screen is then melted by turning steam through the coils and is drained from the bottom of the pan to a rundown tank for further treatment.

Crude scale wax on the first sweating has a melting point which may be varied from 105° to 120° F., and has many commercial uses. If "refined" waxes of higher melting points are desired, further sweating is necessary. When running to refined waxes, the first sweating to crude scale is usually at a melting point between 105° and 109° F. This scale is then resweated for a scale of higher melting point called "resweated scale." The cuts in this case will carry a much higher wax content than those of the slack wax sweating. The resweated scale is again sweated and the residual will be the highest melting point wax desired. The two cuts are also resweated and will give residuals of somewhat lower melting points. Innumerable combinations of resweating are possible, with a wide range of products as to melting point and degree of dryness or oil content. When resweating, the cycles are shorter on account of the lessened quantity of oil remaining to be sweated out in the succeeding steps. A safe rule in figuring oven capacity is to provide for all the slack for a scale wax of about 109° melting point, and then to add 80 per cent. to take care of all resweating for refined waxes if this further step is desired.

Fig. 114 shows the arrangement of a sweating oven of the type described. The building is constructed to give thorough ventilation when cooling down and proper insulation when sweating.

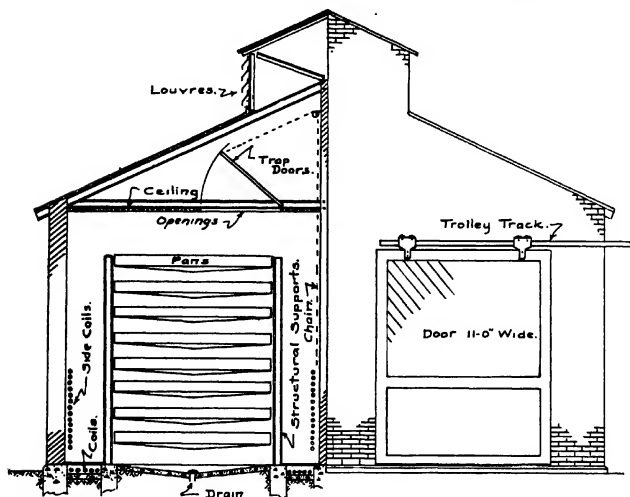
Each stack of 8 pans of above specifications will hold 4,000 gallons of slack wax. The time required from charge to charge, and the capacity of slack wax sweated per day under average



weather conditions and with average equipment, would be as follows:

TABLE 44. OVEN CAPACITIES

Melting Point, °F.	Time, Hrs.	Gallons per Day
105	35	2,740
115	42	2,280
120	45	2,140
125	49	1,960



SECTION A-A ELEVATION DOUBLE OVEN.

FIG. 114

Oven arrangement for double bench of sweat pans.

The above capacities are based on the assumption that the slack contains about 50 per cent. of foots oil. If a very dry cake is obtained from the presses, better time and greater capacities are attainable. For quick cooling and melting down, 0.04 square feet of external pipe area should be allowed for the pan coils per gallon of charging capacity. The side wall coils should have from 0.06 to 0.07 square feet of external surface per gallon charged.

While following similar lines, modern practice in large re-

fineries has progressed considerably. Oven capacities are much greater. Pans are in use from 50 to 60 feet long and 10 feet wide. One result of larger pans, designed pitching from both

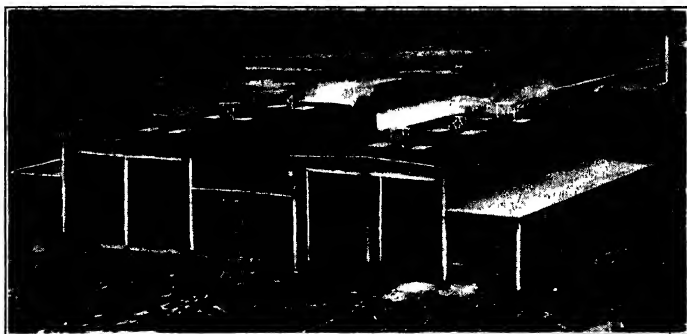


FIG. 115

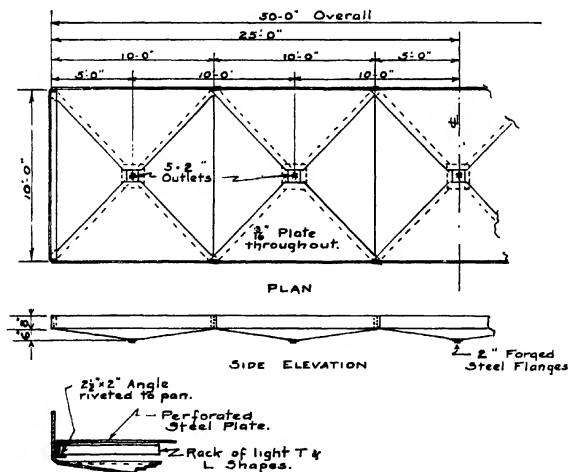
Sweating ovens, Paulsboro, N. J. refinery of the Vacuum Oil Co.

ends to the center, was poor drainage. To overcome this difficulty, pans have been designed with the bottom in the shape of a series of inverted pyramids. Oven capacities have also been increased by placing more pans in the stack. The charging capacity of a 10 by 50 foot pan is about 1,400 gallons. A 10 by 60 foot pan will contain 1,670 gallons. Oven capacities range from 12,000 to 20,000 gallons. Fig. 116 shows a modern 50 foot pan. An assembly 8 pans high is illustrated in Fig. 117.

The costly and troublesome wire gauze screen has been replaced to a large extent by inexpensive perforated metal plates. No. 14 B.W.G. sheet steel, perforated with  $\frac{3}{32}$  inch round holes on  $\frac{3}{16}$  inch centers will give satisfaction.

For sweating purposes hot water, circulated through the coils in the pan, has replaced the use of steam in the side coils of the oven. This system provides much better heat regulation and applies the heat where most effective, directly in the wax cake. The water temperature is not sufficiently high to melt the wax crystals, as would be the case if steam were turned into the coils.

For hot water circulation, a pump capacity of about 20 gallons per minute per 1,000 gallons charged into the ovens is satisfactory. The temperature of the water may be regulated automatically by introducing live or exhaust steam into a tank containing the circulating water. As shown in Fig. 119, a regu-



10' x 50' SWEATING PAN.

FIG. 116

Modern 10 ft. by 50 ft. wax sweating pan.

lator, controlled by the temperature of the water in the tank, actuates a diaphragm valve on the steam inlet. Each oven should be equipped with its own pump, tank and regulator. For smooth operation the tank capacity should be about three times the capacity of the pump in gallons per minute.

In a closed system of water circulation it is very difficult to determine which coils are functioning correctly. For this reason, it is recommended that each coil discharge separately into an overflow trough placed above the top pan and arranged to drain back to the tank for recirculation.

Steam coils along the sides of the ovens are advisable for

two reasons. In the first place, in order to prevent the foots oil from chilling in the run down line, the oven temperature should be maintained about the same as that of the sweating cake. Furthermore, the coils are needed to assist in melting

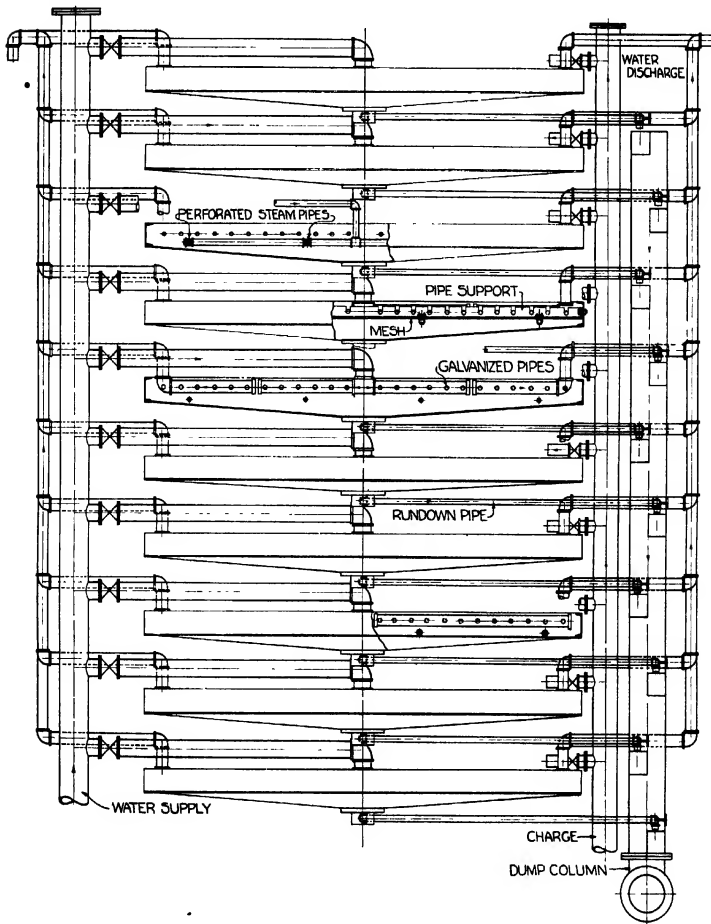


FIG. 117

Assembly of wax sweating pans showing piping.

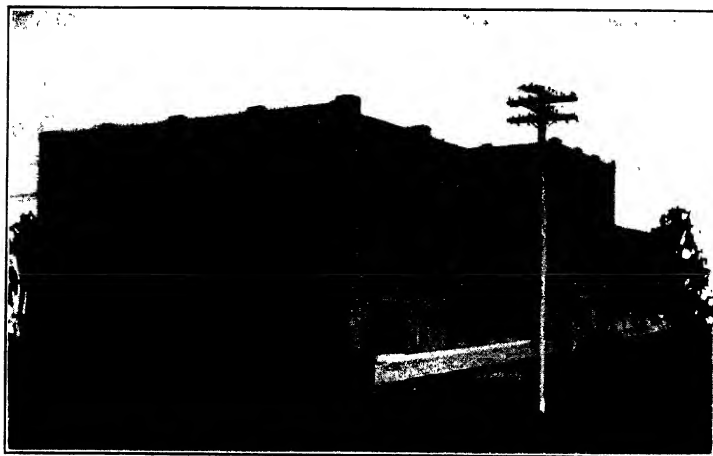


FIG. 118

Sweating ovens at East Chicago. Sinclair Refining Company.

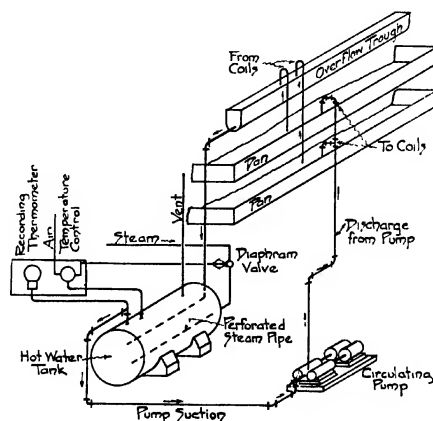


FIG. 119

Diagram of hot water sweating with temperature control.

down the wax after sweating. Obviously, they need not be as large as those required in a system having no hot water circulation. About half the previous figure will suffice. The addition

of an open steam spray under the screen is a valuable aid in melting down.

With hot water circulation, unrestricted outlets, and better ovens, the time cycle has been materially reduced from the figures given for the older type of sweaters. Since the heating surface is proportioned to the charge, the size of batch has very little influence on the number of hours per cycle. In modern practice, with well designed ovens, sweating to scale of 105° M.P. (melting point) requires only 30 hours per cycle. Some companies report as low as 24 hours. For scale of 120° M.P., about 36 hours will be required. In the case of the scale wax of 105° M.P., the 30 hour period is divided as follows:

	Hours
Charging .....	2
Cooling .....	11
Sweating .....	15
Melting down .....	2

For the higher M.P. residual, the extra time is principally in sweating, with a slight increase in time for melting down.

Oven design has changed materially. As originally designed, two stacks were usually placed in a solid brick building with large door openings at either end. In order to increase ventilation when cooling, these doors and the louvres of the roof monitor were opened. The doors also served to allow one pan to be withdrawn for repairs without interfering with others. The rundown tanks were usually buried outside, and the pumps were located in an adjacent building.

With hot water sweating, space for the circulating pumps and tanks was required. This factor, together with the desirability of housing the rundown tanks and transfer pumps, has led to the form of oven arrangement shown in Fig. 120, which is popular today. Troubles due to warping and sagging of the wooden doors covering the end openings, have led some companies to adopt large rolling steel shutters. The ease of operation and reliability of the steel shutters are said to compensate for their lower insulating properties. Steel shutters for this

purpose should be of the type made from a single sheet of corrugated metal. The joints of the interlocking type will quickly rust out on account of moisture coming from the inside of the oven.

One prominent company finds repairs requiring the withdrawal of a pan to be so infrequent that it has eliminated large doors on ovens. In order to obtain the required ventilation while cooling, this concern uses a cold air blast which is released directly over both ends of each layer of molten wax. This blast is

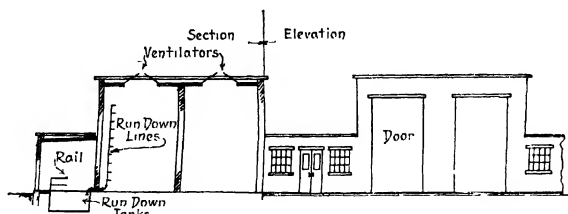


FIG. 120

Modern multiple oven arrangement.

produced by a large motor driven fan. In comparison with other modern ovens, this installation shows approximately 15 per cent. better time results. The increased capacity per oven apparently warrants the additional first and operating costs.

The foots oil obtained from the wax, as above described, may take one of three courses. It may be returned to the stills wherein the wax distillate is re-run, or returned to the re-run wax distillate, or resweated and then returned to the process by one of the two previous methods. In all cases, it eventually finds its way back to the chillers and presses, where the wax extraction starts.

In resweating foots oil, since the sweated product is "slack wax" of similar characteristics to the slack from the presses, much thicker cakes can be treated. This product is more porous and crumbly and allows the oil to percolate to a greater distance. Tank sweaters have been used with success. Rectangular boxes holding 20,000 gallons, packed with coils for water circulation, and shell and tube apparatus with water circulated through the

tubes, have also been used. Pans similar to those for wax, but deeper and with multiple coil layers, are successful. Yields of from 15 to 40 per cent. of slack wax may be taken from foots oil, depending upon the melting points at which the original sweating was done. Obviously, the higher the temperature of the first sweating, the higher the wax content in the foots oil. On account of the comparatively low temperatures (from 90° to 100° F.) at which foots oil is sweated, the work can be done in about one half the time taken for slack sweating.

The scale or refined waxes are sometimes chemically treated in an agitator, usually used for this especial purpose. It is necessary to keep the temperature well above the melting point. For this reason, a tile or hollow brick jacket around the agitator is advisable. Steam coils between the jacket, and closed steam coils in the agitator cone, are used. The treating temperatures are from 150° to 175°. A weak soda solution is all that is usually required. After treating with the soda solution, the batch is washed with hot water and is blown dry with air. The temperature is maintained during the drying. From 7 to 9 hours are usually required for this step, the agitator capacity depending on the daily requirements. No special features of agitator design are necessary except the steep pitch of the cone. This should not be less than 45 deg. As no acids are ordinarily used, a lead lining is not necessary.

With or without treating, it is necessary to filter the wax to obtain a clean white product. Fullers' earth is usually used. The filter bed need not be so deep as that for lubricants. From 6 feet for Pennsylvania wax to 10 feet for some of the North Texas and Louisiana waxes is sufficient. The rate of filtration is also high, six barrels per day per square foot of filter bed area is not uncommon. The yields per ton of clay will vary with the character of the crude from which the wax has been extracted. From 225 to 275 barrels per ton of clay have been reported for Pennsylvania waxes and as low as 100 barrels for the Texas and Louisiana products. The clay usually used has been regenerated 7 or 8 times in lubricating service and may be dis-



carded after one filtration of wax. Except for the fact that the wax filters may be more shallow in relation to their diameter, the design of the filters follows that of those for lubricating oils, as described in Chapter XIII. In order to avoid excessive pumping (a difficult matter with a material which must be kept hot), it is considered good practice to locate the wax filters in the wax plant.

Some refiners prefer the use of bone black for wax filtration, although the newer installations are usually operated on fullers' earth. The use of bone black requires a special furnace for its regeneration. If a filter house for lubricants is not included in the refinery, this is perhaps warranted. Excellent colors and good yields are reported from operations with bone black. It is usually regenerated many times. When fullers' earth from the lubricating filters is no longer suitable for use, or is "spent," it may still be used for wax and afterward discarded. This accounts for the popularity of the fullers' earth method, since practically the only cost involved is the labor of moving the fullers' earth to the wax filters.

After filtration, the wax is ready for packing. Bulk scale wax shipments are usually made in light wooden barrels. The barrels need not be absolutely water tight. Fig. 121 shows a machine that prepares the wax for barreling. A hollow cast iron cylinder 8 or 10 feet long revolves above a pan of the wax, which is kept in a liquid state by a steam or hot water coil in the pan. The cylinder is placed horizontally, so that only a small portion of its circumference is submerged in the wax. Cold water is circulated through stuffing boxes on either end. As the cylinder revolves, a thin film of the hot wax congeals on the surface and is scraped off by a knife held against the cylinder by weights or springs. This thin film of partially chilled wax is quite elastic, and is deflected through a chute into the barrel below. A man tamps it solid as it falls. In some cases the machine is placed on the floor over the packing room and a packing machine similar to those used for packing bran is installed underneath on the packing room floor.

The refined waxes are often moulded into cakes. The hot wax was originally poured into moulds and allowed to cool. Shrinkage caused uneven cakes. The Gray moulding press, Fig. 122, overcomes this difficulty. The operation of this machine is



(Courtesy Carbondale Machine Co.)

FIG. 121

Wax packing machine.

not unlike that of a filter press. Moulds and cooling plates are placed alternately on the frame and "set up" by the ram. The sides of the moulds and frames extend 3 inches above the tops so that an excess of wax may remain above and in communication with each mould. An arrangement is provided to keep this excess wax hot so that it may flow into the moulds to make up for the shrinkage. After the moulds are filled, cold water is circulated through the cooling plates. The wax will chill in from 2 to 3 hours, depending on the melting point. The platen is then drawn back, and by moving the cooling plates along the rods, the wax cakes may be removed.

In order to illustrate the principles of wax plant design, a hypothetical case will be assumed and the requirements worked out in detail. Let it be assumed that a refinery has available 1,200 barrels of good wax distillate per day; and that laboratory or practical tests show that when this is pressed for an 18° cold test oil there is a slack wax yield of 15 per cent.

Fig. 123 shows the process to be followed. Only one grade of scale wax is desired, of about 109° M.P. The losses are not shown, as they amount to only 1 or 1½ per cent. at each step and would not influence the selection of equipment.



FIG. 122

Gray moulding machine for wax cakes.

The capacity figures for refrigeration, chillers and presses all include an allowance for the returned foots oil. In this case, therefore,

$$\text{Refrigeration} = \frac{1,200}{8} = 150 \text{ tons,}$$

$$\text{Chillers} = \frac{1,200}{25} = 48 \text{ sections.}$$

Four 12-section machines will do. Two press plates per barrel per day at 20 per cent. wax content and one at 10 per cent. wax content are required. At 15 per cent. wax content, 1.5 plates will suffice.

$$\text{Plates} = 1,200 \times 1.5 = 1,800.$$

The required capacity might be obtained, therefore, by using

presses of 300, 360, or 450 plates in groups of six, five, and four, respectively. Since five or six presses would be more expensive to install and would require more frequent dumping, four 450-plate presses will be selected.

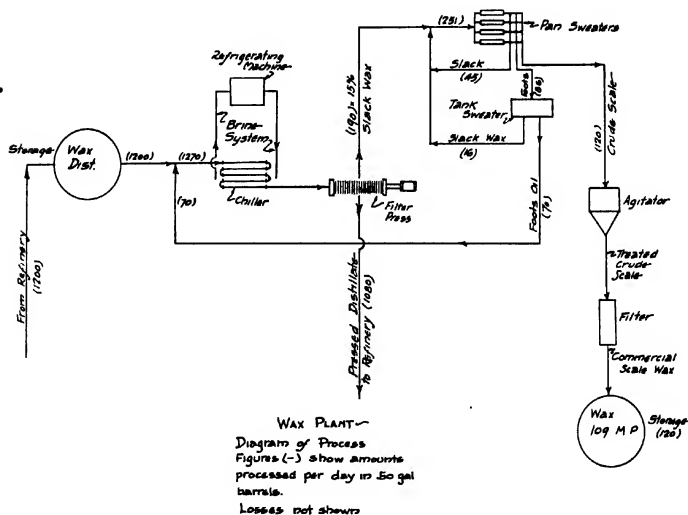


FIG. 123

The daily oven requirements are for 251 barrels or 12,500 gallons. A  $10 \times 50$  foot pan will charge 1,400 gallons. For  $109^\circ$  M.P. wax, 32 hours should be allowed per cycle. The daily pan capacity will be, therefore,

$$1,400 \times \frac{24}{32} = 1,050 \text{ gallons.}$$

The number of pans required will be

$$\frac{12,550}{1,050} = 12.$$

Two ovens of 6 pans each, with sufficient headroom to allow for two additional future pans in each oven, will be satisfactory.

In addition, a foots oil sweater of the tank type charging

4,300 gallons will be required, or an oven of about 6 additional pans similar to the wax pans may be used.

For treating the wax, one batch per day, an agitator of 125 barrels' capacity will be required. To allow for occasional interruptions of treating and for future growth it would be advisable to increase the agitator capacity to about 250 barrels.

The required filter area is

$$\frac{120}{6} = 20 \text{ sq. ft.}$$

A filter tank 5 feet in diameter by 10 feet deep will do this work. To allow for washing the filter and replacing the clay, this equipment should be installed in duplicate.

Auxiliary equipment will consist of tanks, pumps, packing equipment, and miscellaneous smaller items. Since all the stocks shown on the diagram are intermediate except the finished wax, from 7 to 10 days' tank storage capacity should suffice for each. In the case of finished wax, tankage for 60 days' storage should be provided. Three 2,500 barrel tanks are recommended. The selection of three small tanks instead of one or two larger ones is made to provide for the production of more than one grade of the finished wax if such a policy should eventually be found desirable.

## CHAPTER XIII

### FILTERING

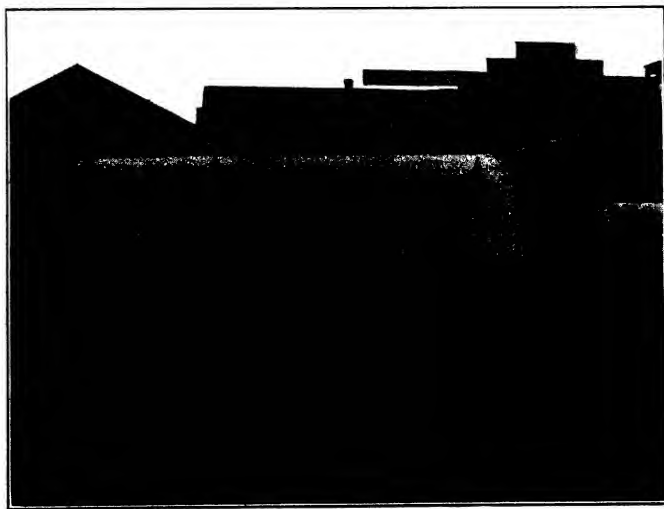
Object—Process—Fullers' earth—Rates of filtering—Apparatus—General arrangement—Yields from clay—Filter cycles—Regeneration of clay—Clay bins—Notes on conveying systems.

Filtering or percolation through fullers' earth is one of the usual means of improving the color of petroleum products. There is much controversy as to the relation between color and value in lubricating oils. Except as an indication of the possibility of the presence of unsaturated compounds, which are liable to break down under heat and release free carbon, color bears no apparent close relation to the quality of a lubricant. Moreover, this indication is by no means infallible. Trade demands are often responsible for efforts toward improving the color of a lubricant which would nevertheless be satisfactory with a lower color standard. Most lubricating oils are, therefore, subjected to filtration through fullers' earth, the so-called "filter clay." Extensive beds of this material are located in Florida and in one or two of our Western states. It is crushed and screened to size and shipped to the refineries in bulk or in burlap bags.

The size of the clay particles depends upon individual preference. Clay passing through a sieve of 40 meshes per lineal inch but retained on a 60-mesh sieve (known as "40-60 clay") is extensively used. Excellent results are reported with 60-90 clay, although with oils of high viscosity, the rate of filtration is slow. For such oils, 30-60 or 40-60 clay is generally preferred. Since the fine clays require greater head to produce a steady flow they are not well adapted to gravity feed filters. In general, it appears that the finer the clay, the higher is its efficiency as a decolorizing agent. The degree of fineness is limited by practical mechanical difficulties. Clay pulverized to a dust is very effi-

cient and filters adapted to the use of such material are in process of development.

The action which takes place in a filter is the subject of much discussion. According to some authorities, the action is chemical, while in the opinion of others it is entirely physical. It is probably both chemical and physical. Chemical reaction is often indicated by a material increase in temperature between the incoming and the outcoming oil at the start of the run. After a time there is no further apparent increase and beyond this point the action is probably physical.<sup>1</sup>



(Courtesy Hammond Iron Works.)

FIG. 124

Small oil filter.

Filter clay, as received from the mines, contains upward of 5 per cent. moisture, which must be removed prior to use. This is accomplished in kilns of various types. The complete removal of moisture is necessary for satisfactory results in the filters. A

<sup>1</sup> For a theoretical discussion of decolorization by filtering, see Bacon and Hamor, *American Petroleum Industry*, p. 614.

cubic foot of raw or "green" clay of 30-60 mesh has an average weight of about 35 lbs. After a preliminary "burning" to remove the moisture, the weight becomes 33 lbs. per cubic foot, indicating a moisture content when received from the mines of 6 per cent.

Some clays are found to have a more active decolorizing effect on certain oils, if the water of constitution is also removed. Mr. T. T. Gray reports the average loss in weight of 12 samples of 60-90 clay when burned in laboratory apparatus at a dull red heat as 13.2 per cent. From 5 to 6 per cent. of loss is due to contained moisture, the balance being the water of constitution.

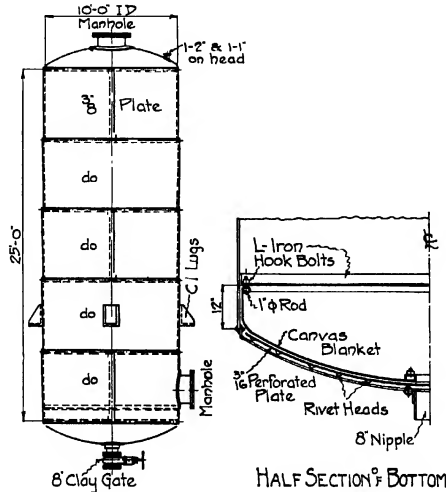


FIG. 125  
32-ton filter.

The vertical type of filter is generally used. A canvas blanket over a perforated drainage plate is provided to hold the clay, the oil passing on through the outlet. Manholes for charging and discharging the clay and the necessary pipe connections are provided. Fig. 124 shows a small filter. Construction details for a larger unit are shown in Fig. 125. The



pressures employed in filtering are low. In order to provide sufficient strength for blowing out with air pressure and for steaming, filters should be designed, however, for a pressure of from 40 to 50 pounds per square inch.

The filtering rate and corresponding capacity vary with the stock and the fineness of the earth. In general, the greater the amount of color to be removed, the greater is the amount of clay necessary. The filtering rate may be expressed in terms of the quantity of oil per square foot of sectional area of the filter per unit of time. The following rates are typical:

	Bbls per Sq Ft per Day
Cylinder stocks .....	0.6
South Texas lubricants .....	0.7
Pressed neutral oils .....	0.8
Wax .....	.4 to 6

The rate of flow of a given filter depends, therefore, upon the diameter. The depth must be sufficient to provide a suitable length of contact between the oil and the clay, and for most oils should be about 15 feet. For wax a depth of 5 or 6 feet is sufficient. Another factor enters into the question of depth. Increasing the depth provides greater clay charging capacity, and, consequently, lengthens the possible run before the filter must be dumped and recharged. The increased length of run will result in greater throughput per annum. There is a practical limit of about 30 feet to the depth, above which limit channeling of the oil is liable to occur. As a guide in the selection of filters, the following table is offered:

TABLE 45. FILTER CAPACITIES

Diameter, Feet	Depth, Feet	Charging Capacity, Tons of Clay	Rate of Flow, Gallons per Minute			Average Throughput, Barrels per Day (Aver- aged over the year)		
			I	II	III	I	II	III
6	15	7	0.50	0.58	0.66	10	14	13
8	20	17	0.88	1.03	1.18	19	26	25
8	25	21	0.88	1.03	1.18	20	27	26
10	20	25	1.38	1.61	1.84	27	38	36
10	25	32	1.38	1.61	1.84	29	41	38
10	30	38	1.38	1.61	1.84	31	43	40

In the above table, the rates of flow and daily averaged throughput take into account the yields for the various products, as follows:

- I. Cylinder stocks.
- II. Paraffine oils.
- III. Neutral oils.

Since the greater the yield obtained, the lower is the percentage of idle time, the yields directly affect the possible throughput. The clay charging capacities are based on "fresh" earth, that is, earth which has been dried to remove the water content but which has not been previously used for filtering. Clay which has been used and subsequently burned or regenerated for further use is heavier than the fresh earth, so that the capacity in tons with burned clay is greater than the tabular value. This increase in weight will be further discussed in connection with the subject of regeneration of the earth.

No fixed standards for yields per ton of clay can be established. The yields will vary with different stocks and also with different grades of the same stock, depending upon the previous handling and the desired color reduction. The quality of the clay also has its influence. Fresh clay is best adapted to the manufacture of light colored oils, while for a lesser decolorizing effect a good yield may be obtained with clay regenerated one or more times. Seven or eight burnings is about the present limit for lubricants, after which the clay may be used for wax or sometimes for refined oils. It is customary to classify the clay by numbers indicating successive regenerations. Thus "number one" clay has been burned once, besides the original dehydration, "number two" clay twice, and so on.

Another system which has the advantage of giving a symbol for the clay at each separate stage of its life, is as follows:

	Number
New clay .....	0
New clay dehydrated .....	$\frac{1}{2}$
New clay dehydrated and used once .....	1
Above after regeneration .....	$1\frac{1}{2}$
Above again used .....	2
Above after regeneration, .....	$2\frac{1}{2}$
Etc.	

Typical yields with different qualities of clay are as follows:

TABLE 46. FILTER CLAY YIELDS

Stock	Color No	Yield, Barrels per Ton of Clay	Clay No.
Light spindle . . . . .	1	4	2
Medium spindle . . . . .	2½	6	3
Dark spindle . . . . .	3	8-10	5
Light red oils . . . . .	5	12-15	1
Dark red oils . . . . .	6	19-21	2 and 3
Cylinder stocks . . . . .	—	7-10	1
Wax . . . . .	—	20-30	7 and 8

Colors numbered according to National Petroleum Association standard.

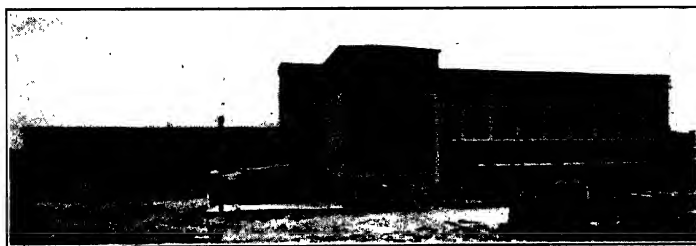
While these yields are subject to great variation, depending on the original color of the stock and the final color desired, they are fairly representative for these classes of stock. In the table of filter capacities, the oils are grouped under three classifications, and the figures are based upon average conditions. The figures may be used with safety, since every installation will have several filters, so that the retarded operation of one unit will usually be balanced by better results obtained from others.

Filters may be operated with gravity or pressure feed. The latter is preferred in modern practice. The operation of a pressure feed filter is usually as follows: After the filter has been charged with clay, oil is pumped in under a pressure of 5 or 6 pounds per square inch until the oil "shows through." The time required for this operation will depend upon the viscosity of the stock, the shape of the filter and the fineness of the clay. The pressure may then be increased to 15 pounds per square inch and the filter will settle down to a steady rate of flow. The oil first through or "off" will show color well above that desired. As the filtration continues, the filtrate gradually becomes darker until the blended filtrate finally reaches the color standard established.

It is often possible to continue the operation of the filter after the stock originally desired is off, by segregating further filtrates for use in blending other products. Since it decreases idle equipment time and thus provides for a greater average throughput,

this method is always desirable. The possible length of run will be determined by the rate of flow, the filter charging capacity in tons of clay, and the yield of stock obtainable from the clay. This may be approximated from the tabular data given above.

After the run is finished, air pressure may be applied to assist in draining the filter. Even with the use of air, the drainage will take several hours. In order to abstract the coloring matter from the clay, light naphtha is then pumped through the filters. From 6 to 7 barrels are required per ton of earth. Steam is introduced to displace the naphtha, leaving only the heavier tarry bodies which are intimately absorbed by the clay. The steaming process usually requires from 15 to 18 hours. The amount of steam necessary varies. Some refiners report as high as 900 pounds per ton of clay, but 500 pounds per ton is generally sufficient. From 30 to 55 pounds per ton per hour may be used in calculating steam mains. The clay tonnage of the maximum number of filters to be steamed at one time can be readily estimated.



(Courtesy Turner Construction Co.)

FIG. 126

Filter plant of the Vacuum Oil Co. at Paulsboro, N. J. Burner house at left, concrete clay bins center and filter house at right.

The steam and naphtha vapors leaving the filter should be condensed in suitable surface or jet condensers and passed through a trap where the naphtha may be continuously reclaimed from the water and returned to the wash tank. After

several washings, the naphtha is re-run, leaving in the still a dark stock which may be utilized for various products.

After steaming, the filter is dumped, inspected, closed and recharged. In large filter houses with conveying systems this step is of short duration. For filters up to 20 or 25 tons' capacity, it is practical to install conveyors large enough to handle the entire charge or discharge in one hour. For larger sizes, the cost of a conveying system sufficiently large to handle the clay in one hour should be balanced against the cost of idle time.

Idle time is usually a large item in filter plant operation. As an example of a filter cycle, the operation of a 25 ton filter operating on a neutral oil will be considered in detail.

The filtrates and yields from one ton of clay are:

	Bbls
Light spindle .....	4
Medium spindle .....	6

The periods required for each step in the process are:

	Hours
Fill and show through .....	18
Light spindle filtrate .....	40
Dark spindle filtrate .....	60
Drain with air .....	25
Wash and steam .....	32
Dump, inspect and charge .....	4
Total cycle .....	179

Idle time, per cent.,

$$\frac{79}{179} = 44.1.$$

Since the time actually consumed in filtering depends upon the yield of filtrate from the clay, it is obvious that with such oils as cylinder stocks, a shorter cycle will result. For instance, an oil from which one ton of clay yields only three barrels will go off color in about thirty hours and no further filtration will be provided without recharging. Since the periods for the other steps will be about the same, the cycle will approximate 109 hours, and the idle time will amount to 72 per cent.

Oils of high viscosity, particularly cylinder stocks, are usually filtered in a solution of naphtha. Various ratios of naphtha to stock are reported. In most cases, the stock is from 30 to

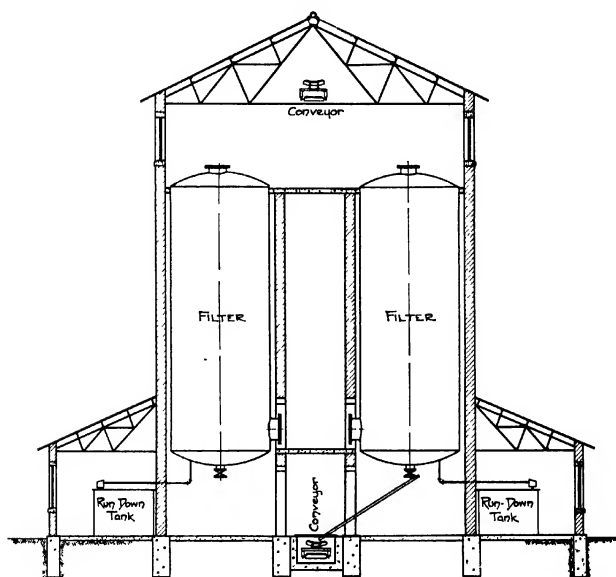


FIG. 127

Section of filter house.

40 per cent. of the combined total. The mixing of the stock and naphtha may be accomplished by introducing the discharge from each pump into a mixing header connected to the battery of filters. The two pumps may then be regulated to give the desired ratio. For cylinder stocks which are subsequently to be cold settled, filtering in solution entails practically no extra expense, since, in any case, the stock would be diluted with naphtha prior to settling. The naphtha is usually removed from the oil after filtering by steam distillation.

The conventional arrangement of large filter houses is shown in Fig. 127. The service piping is illustrated in detail in Fig.

128. An arrangement suitable for a small filter plant is shown in Fig. 129.

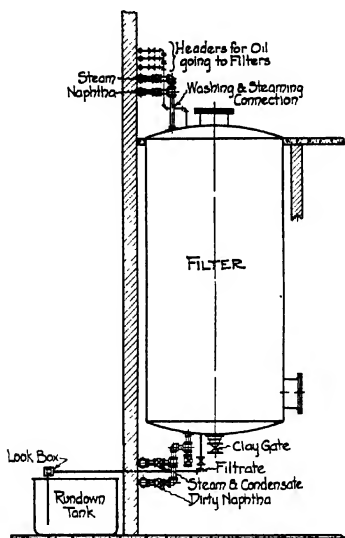


FIG. 128

Service piping for filters.

Filtration temperatures will vary greatly. Certain oils must be handled quite hot, while with others, equally good results are obtained at normal temperatures. Ample steam coil radiating surface should be provided in the filter compartments in all cases where the requirements are doubtful. In general, cylinder stocks require the highest temperature and the temperatures for other oils vary somewhat according to viscosity.

Mention has heretofore been made of the regeneration of the spent earth from the filters. The process is one of burning the tarry coloring matter out of the pores of the clay at a temperature sufficient to accomplish this result but not high enough to disintegrate the clay. Pyrometers are essential to maintain the correct temperatures. Average temperatures from 600° to 750° F. are found satisfactory. The allowable maximum is about

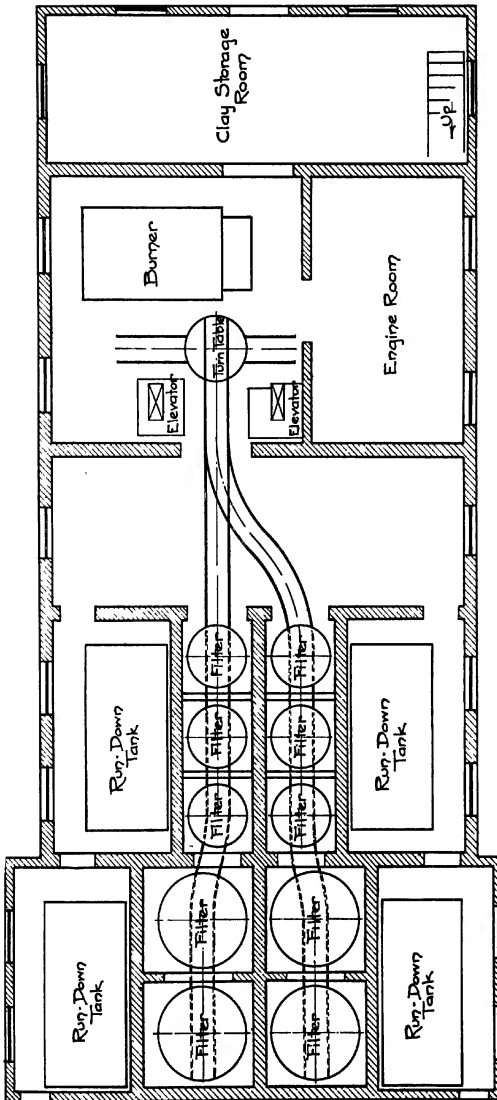


FIG. 129  
Arrangement of small filter house.



950° F. Above 950°, the clay becomes vitrified and its decolorizing power is decreased. G. G. Brockway states that an overburn of 300° F. will reduce filtering capacity 30 per cent.



*(Courtesy Turner Construction Co)*

FIG. 130

Modern filter plant.

The two general types of apparatus now in use for regenerating the clay are the vertical gravity oven and the rotary kiln. The Brockway New Century (U. S. patent 978625) and the Kuebler (U. S. patent 919598), shown in Figs. 131 and 132, are types representative of the vertical gravity oven. The advantages claimed for this type of oven are small floor space, a minimum number of moving parts, low first cost and small maintenance expense. The fuel consumption in the New Century dryer is said to be from 6 to 10 gallons of fuel oil per ton of clay. The capacity of the New Century furnace illustrated is 24 tons of clay per 24 hours. That of the Kuebler is 10 tons per 24 hours. These capacities are for clay previously used in the filters. When drying green clay, somewhat greater throughputs may be expected.

The rotary kiln is preferred by some refiners. Fig. 133 shows a kiln manufactured by the Bonnot Company. A steel shell lined with refractory material is mounted on rollers and revolved by a train of gears. The kiln is inclined, the clay entering at the rear or high end and discharging from the cylinder through the bottom of the movable housing, placed at the low or front end.

Burners are introduced through the housing, the products of combustion leaving the kiln through the rear stationary housing and stack.

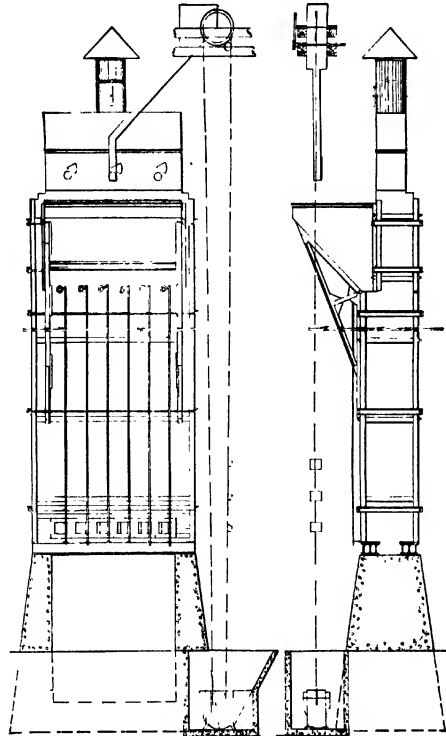


FIG. 131  
New Century dryer.

After leaving the kiln, the clay must be cooled to approximately 130° to 150° F. for safe and convenient handling. A rotary cooler is placed beneath the kiln with draft supplied by a separate stack. The general arrangement is shown in Fig. 134

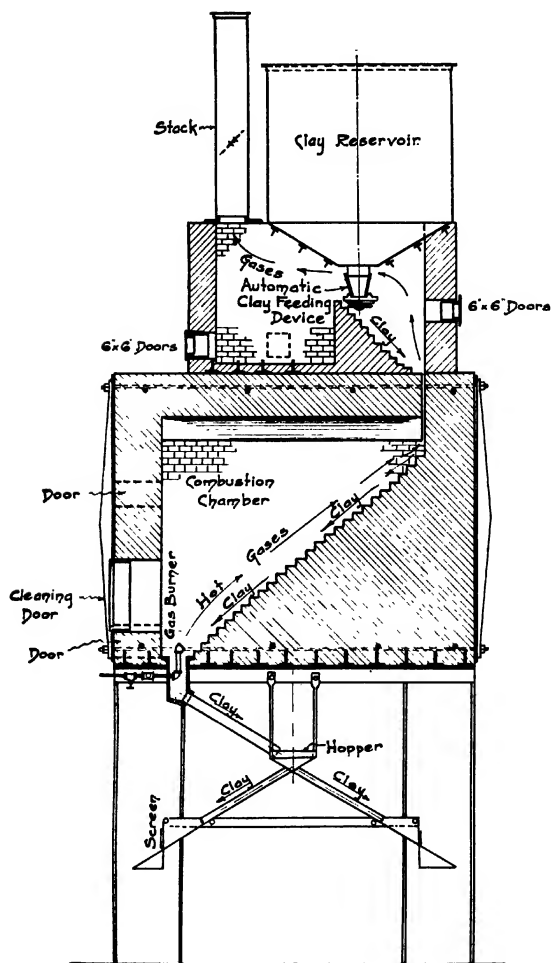


FIG. 132

Kuebler clay burner.

The standard sizes manufactured by this company are as follows:

TABLE 47. SIZE AND CAPACITY OF ROTARY KILNS

Diameter, Ft.	Length, Ft.	Capacity, Tons per Hr.
4	40	1
5	40	2
6	40	3
6	60	4

Few refiners operate kilns of this type at such high capacities. Present practice is usually limited to about 25 per cent. of the above ratings when burning clay from the filters and 40 per cent. when dehydrating green earth, although rates of 40 per cent. and 60 per cent. are occasionally reported.

The fuel consumption of rotary kilns is from 10 to 12 gallons



FIG. 133

Bonnot rotary kiln.

of fuel oil (38° B.) per ton of clay burned. As in the case of the vertical gravity furnaces, gas or oil fuel is best adapted to this service. Mechanical or air atomizing oil burners are recommended. Little success is reported with steam atomizing burners.

The clay burning capacity required for filter plants depends upon several factors. In general, one ton per hour per 300 tons of clay charging capacity will suffice. This figure will allow sufficient excess capacity for the dehydration of the green clay. It applies only to plants operating on an average line of products resulting from the natural yields of the crude, such as neutrals, red oils and a moderate proportion of cylinder stocks, and when using filters of from 25 to 30 tons' capacity. When filtering a larger proportion of cylinder stocks or oils of similar character,

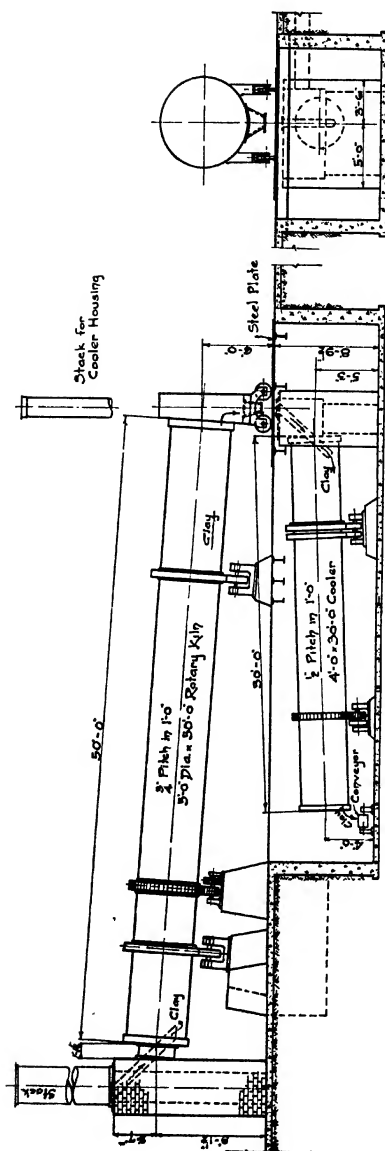


FIG. 134

Arrangement of rotary kiln and cooler.

or where the yields per ton of clay are below average, or the filters are small, resulting in short cycles, the clay burning capacity should be increased to one ton per hour per 200 tons of filter charging capacity.

As previously stated, the clay will increase in weight with successive burnings. Reports on 30-60 mesh clay are as follows:

• TABLE 48. EFFECT ON WEIGHT OF BURNING 30-60 CLAY

	Lbs. per Cu. Ft.
Green clay .....	35
Fresh dehydrated clay .....	33
No. 1 clay .....	35
No. 2 clay .....	36
No. 3 clay .....	33
No. 4 clay .....	39
No. 5 clay .....	40
No. 6 clay .....	40

After the fifth or sixth burning, no further increase in weight becomes apparent.

It is the custom of some refiners to use clay over and over, successively, adding make-ups of fresh clay to each charge. The larger filter plants, however, with many filters in operation on various stocks, segregate the clays in separate bins according to the number of times they have been burned. The clay is usually discarded after seven or eight burnings.

If it is desired to segregate the clay, two bins should be provided for each grade, one for the dry burned clay ready for the filters, the other for the wet clay from the filters. In addition, one or more bins each for the fresh clay and the green clay should be provided. It is poor economy to reduce the number of bins and rely on feeding a filter from a kiln or vice versa. The slow burning rate will result in excessive idle filter time, with consequent extensive outlay for additional equipment. Assuming that the clay is discarded after seven burnings, a minimum of 16 bins is required. If they are of a uniform size, one additional bin each for green and fresh clay is advisable to furnish extra storage capacity for these grades, making a total of 18 bins. The individual bin capacity should be slightly in excess of the charging capacity of one filter. If large extensions are

probable, a capacity for each bin, slightly greater than the combined charging capacities of two filters, is good policy. If first cost is of vital importance, however, future filter installations may be provided for by the construction of additional bins as required.

A rule for bin capacities which has been used with success is as follows:

New clay, one large bin.

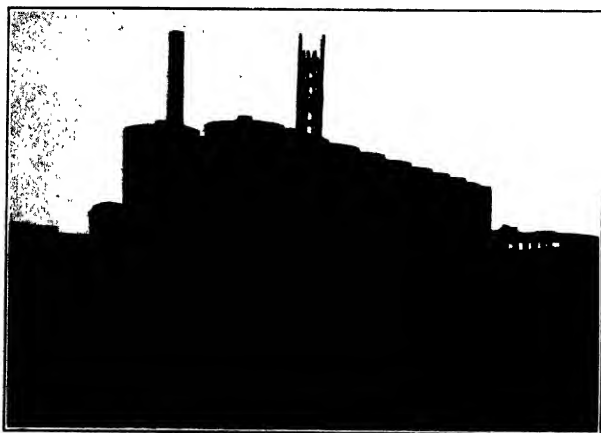
New burned clay, two bins.

Unburned clay from filters, two bins for each retort.

Burned clay, ready for filters, two bins for each retort.

Spent clay, one bin.

For example, a plant with two retorts should have a large new clay storage bin and eleven smaller bins. In order to avoid delays, this arrangement will require closer attention from the plant operator than that previously described.



(Courtesy Hammond Iron Works.)

FIG. 135

Filters being erected.

Clay bins have been successfully constructed of both steel and reinforced concrete. The design follows conventional practice. The weights of the clay are given above. The angle of

repose for burned clay may be taken at 35 degrees. The minimum inclination for chutes and spouts should be 40 degrees from the horizontal. An inclination of 45 degrees is preferable.

As previously mentioned, presupposing a reasonable first cost, the conveying system should be designed to transfer clay to and from the filters in the least possible time. The rate of transfer from kilns to storage is closely established. In the selection of conveying and elevating apparatus, a few practical considerations, the outgrowth of experience, are of interest. Since filter clay is abrasive, elevator buckets mounted on chains moving over sprockets are not satisfactory. Buckets riveted to 6-ply stitched and oiled canvas belting running over pulleys give good results. Troughed conveyor belts are recommended, although some refiners prefer the flat type. Higher capacities for a given investment are possible with the former. Stitched and oiled 4-ply canvas belts are well adapted for the conveyor use.



## CHAPTER XIV

### COLD SETTLING

Object of process—Application—Types of settling apparatus—Details of process—Cooling required—Capacities—Typical results—The centrifugal process.

Residual cylinder stocks contain a considerable quantity of wax which has not been removed with the wax distillate cut. Since the residual stock has been run with every effort to avoid cracking, the wax is in an amorphous state. The cold test of such residual stocks varies from 20° F. or less up to 50° or 60° F. After decolorization by filtration or other means, the cold test often rises to 80° or 100° F. on account of the removal of the asphaltic bodies which reduce the congealing tendencies of the amorphous wax.

The viscous cylinder stocks may be compounded with neutral and other mineral oils into many grades of lubricants, such as automobile oils. It is necessary to remove the asphaltic bodies, however, and the resulting high cold test is objectionable. In order to produce these "bright stocks" with satisfactory cold tests, the process known as *cold settling* is adopted.

In the early days of refining, the storage of paraffine base crude oils during cold winter weather often resulted in a separation of the amorphous wax. Upon the distillation of the crude oil from which the wax had settled, the resulting cylinder stocks were found to have an improved cold test and a consequent higher value. This fact led to experiments in producing similar results artificially. The modern process of *cold settling* is the outcome.

Two types of settling apparatus, the box type and the tank settler, are now in use. The box type is the older system. In this apparatus, the cylinder stock, in solution as later discussed, is placed in rectangular tanks, in rooms provided with refrigerating coils. The temperature is maintained at 0° F. This

system apparently attempts to reproduce the conditions whereby the oils were naturally settled during winter storage. It requires expensive building construction and excess refrigerating capacity, and is slow of operation.

These objections have led to the tank type of apparatus which is in general use today. A standard vertical cylindrical tank is used. The depth of the tank is from 80 to 85 per cent. of the diameter, and the capacity from 10,000 to 80,000 gallons. Coils for circulating the cooling medium are provided in horizontal layers at the top. Suitable insulation protected by brick or tile jackets is essential. Efficient sampling devices at close intervals from the bottom of the tank half way to the top are necessary to enable the operator to differentiate between the settled stocks and the petrolatum (the amorphous wax) and to arrange his draw-offs accordingly. The outlets for bright stock should be so arranged that the contents of the tank may be drawn from the different strata. A tank charging 500 barrels is shown in Fig. 136. In place of various outlet pipes, some refiners use an adjustable suction pipe inside of the tank provided with a level indicator on the outside. This suction pipe carries a spider which draws the oil from several points. Close separation and a minimum disturbance of the contents are provided by this arrangement.

The coils are placed as near the roof as possible. Brine is used for chilling. The brine temperature is usually from 10° to 20° F. Coils of relatively small diameter, from 1½ inch to 2 inches, are better than an equal amount of surface with larger pipe. Twenty-five square feet of surface per one thousand gallons of charging capacity is satisfactory. The coils may be supported on structural framing within the tank, or suspended from the roof. Since columns and struts in the body of the tank are liable to disturb the quiet, uniform action desired, roof suspension for the coils or I-beam supports of clear span are preferred.

Theoretically, the refrigeration required per 1,000 gallons of stock and naphtha is approximately 1.1 tons for the complete

cycle. The refrigeration will vary with different proportions of naphtha and stock and with the yield of petrolatum. The latter will depend upon the desired cold test of the stock. From

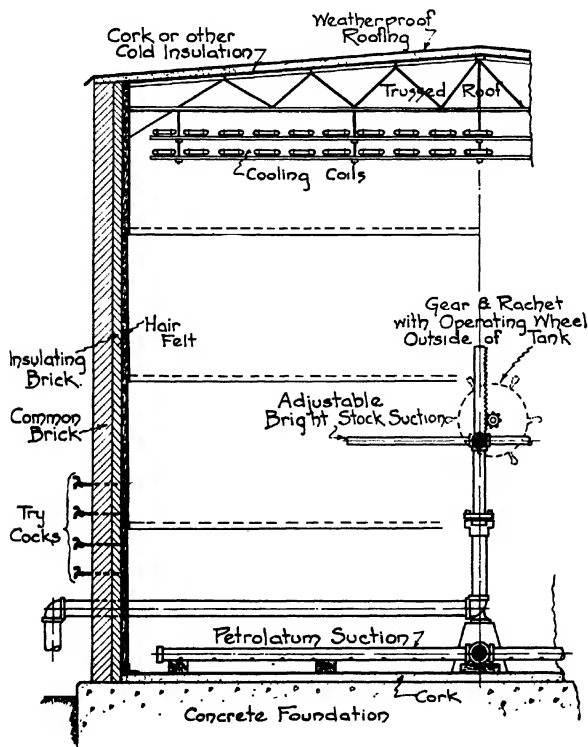


FIG. 136

Section of tank settler.

1.8 to 2.0 tons of refrigeration per 1,000 gallons will cover such variations as well as the heat losses, if satisfactory insulation is applied. Ordinarily, for multiple unit plants, a refrigerating capacity of three quarters of a ton per day per 1,000 gallons of total charging capacity (cylinder stock and naphtha) will suffice.

The operation is usually conducted as follows. Best results are obtained if the stock and naphtha are charged into the tanks at a temperature of from 90° to 100° F. This temperature may be obtained by a steam heated double pipe or shell and tube interchanger on the charging line. After charging, the settling tank is gradually cooled down, the petrolatum settling and accumulating at the bottom. At the start, water may be used in the coils. Where a battery of several settlers is in use, further economy of refrigeration is sometimes gained by pumping the cold settled oil from a tank being emptied through an auxiliary set of coils in a tank being cooled down.

When the oil is cooled to 8° or 10° F., the refrigeration is stopped and the mass is allowed to settle for 24 hours. The stock is then pumped off through the upper suction lines or the movable suction pipe which is adjusted above the petrolatum level as determined by the sample cocks. At this point some refiners remove a second portion of stock lying between that ad-

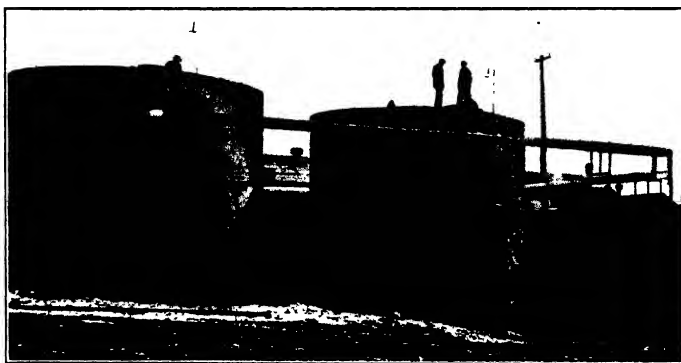


FIG. 137

Cold settling tanks of Tiona Refining Company at Clarendon, Pa.

judged as standard and the petrolatum. This stock is termed "half-settled," and is introduced into the settling apparatus with the next batch. After drawing off the stock the bottoms are pumped off as petrolatum. The naphtha in each fraction is removed by steam distillation in the usual way, the bottoms

from the stills being the "bright cylinder stocks" and petrolatum. The bright stocks are then ready for compounding into various cylinder and motor oils. The petrolatum, after decolorization and treatment, is the basis of the various petroleum jellies and ointments.

The time for a cycle of a cold settling tank is from 4 to 6 days. Since a high cold test will not require so much time as a lower test, the desired cold test of the bright stock will influence the time. For a given unsettled stock, the lower the cold test desired, the greater will be the yield of petrolatum.

For cylinder stocks made from Pennsylvania crude oil typical results from the cold settling process are as follows:

TABLE 49. TESTS AND YIELDS. COLD SETTLING

	No 1	No 2
Cold test of charge, ° F. ....	80	50
Yield of bright stock, per cent. ....	85	73
Cold test of bright stock, ° F. ....	50	38
Yield of petrolatum, per cent. ....	15	27
Melting point of petrolatum, ° F. ....	115-117	118-120

The operation of cold settling as above described is not as simple as the description indicates. Since the gravity of the mixture of bright stock and naphtha is very nearly the same as that of the mixture of petrolatum and naphtha, any disturbance to the mass during settling is liable to throw the batch "off." As it is necessary to start the settling at the relatively high temperatures, before mentioned, of 90° to 100° F., it is obvious that considerable trouble may result if the mixture is disturbed and then has to be reprocessed.

Recent adaptations of the centrifuge to the manufacture of bright stocks have attracted considerable attention. The advantages claimed for the centrifuge method are continuous operation, lower cold test for the bright stock, better yield of bright stock and a higher quality of petrolatum.

Fig. 138 shows the Sharples process. The mixture of 60 per cent. naphtha and 40 per cent. cylinder stock is heated, as in settlers of the tank type, to 100° F., and is then cooled in the chilling tanks to minus 10° F., over a period of 48 hours. From



the chilling tanks, the stock passes to the primary centrifuges. In order to effect the continuous discharge of the wax (petrolatum) from the centrifuge, a carrier liquid heavier than either stock or petrolatum is necessary, which will form a layer on the periphery of the rotor. Brine or water is used for this purpose.



FIG. 139

Installation of Sharples centrifuges.

The wax free oil, and a mixture of petrolatum and brine or water, are then discharged continuously from two distinct outlets. After passing through heat exchangers to conserve refrigeration the cold wax free cylinder stock is carried to storage and the naphtha is subsequently removed by distillation as in the tank type settlers. The petrolatum and brine are heated by steam, the wax rising to the surface and flowing to storage. This wax, however, must be further dehydrated and this is done in a second-

ary centrifuge at a temperature of 150° F. After the second centrifuging, the mixture is reduced to reclaim the naphtha, the residual being commercial petrolatum.

The commercial units manufactured by the Sharples Specialty Company will process 55 barrels of combined naphtha and

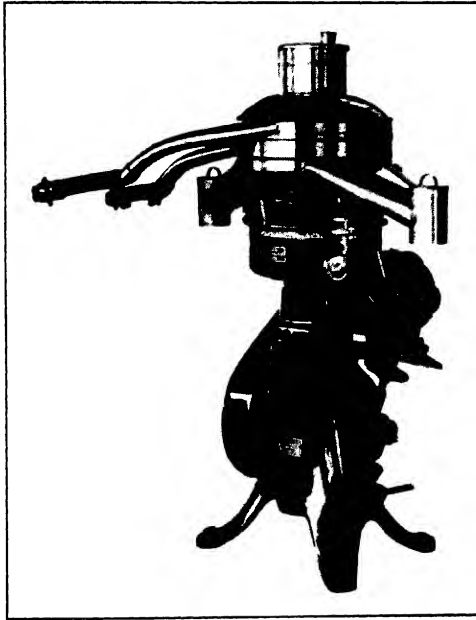


FIG. 140

De Laval centrifuge for manufacture of bright stock.

stock per day. From green stocks adapted to the previously described methods of settling, yields of from 85 to 95 per cent. of bright stock are reported with a pour test of from 15° to 30° F. The Sharples units operate at 17,000 r.p.m., requiring a power input of 1 K.W. per hour each. Four tons of refrigera-



tion per 24 hours are necessary for each unit. Fig. 139 shows a commercial installation of this process.

The De Laval Separator Company's apparatus is shown in Fig. 140. It differs from the Sharples system principally in the elimination of the carrier liquid. The bright stock and petrolatum are therefore ready for steam distillation as received from the separators, without further centrifuging.

## CHAPTER XV

### COMPOUNDING

Object—Meeting specifications—Animal and vegetable oils—Plant requirements—Greases—Barrel preparation—Barrel filling—Can filling—Barrel house practice.

Compounding is the term usually applied to the process of mixing together two or more petroleum stocks in the manufacture of lubricants. Animal or vegetable oils are also frequently added. The mixing of naphthas, burning oils and fuel oils to meet various specifications is termed *blending*. Blending is a simple operation requiring no elaborate equipment, and is often accomplished on a small scale in the shipping or barrelling tanks.

Lubricants, however, demand more attention. They are compounded to meet specifications for gravity, viscosity, cold test and color, and for special uses. The various formulas for lubricants are innumerable and beyond the scope of this volume.

In order to meet gravity specifications, oils may be mixed in direct proportion by weight. Flash and fire tests will remain nearer that of the portion having the lowest tests. High cold and pour tests may be reduced by mixing with oils of lower test, but not, by any means, in direct proportion. No rules of general application have been evolved on this subject. The nature of the stocks obtained from different crudes has considerable influence upon results.

Compounding is practiced principally in order to meet viscosity specifications. The viscosity of a mixture cannot be calculated by the law of direct proportions. It is lower than that shown by proportional calculations. For instance, it might be assumed that the viscosity of a mixture of 50 per cent. of 100 viscosity oil and 50 per cent. of 200 viscosity oil would be 150. The actual viscosity will be about 137. Considerable study has been spent on this subject and formulas and charts are available from which the percentages of oils of various viscosities

required to produce a mixture meeting the viscosity specifications may be determined.<sup>1</sup>

Various oils other than mineral oils are used to meet certain conditions. Cylinder oil, for instance, compounded with from 5 to 7 per cent. of tallow, adheres more closely to the metal surfaces and produces a greater lubricating effect than the mineral oil alone. Other animal oils, such as neats-foot, lard, sperm and fish oils are sometimes used. Linseed, rape, cotton seed, and castor oil are the vegetable oils commonly used in compounding.

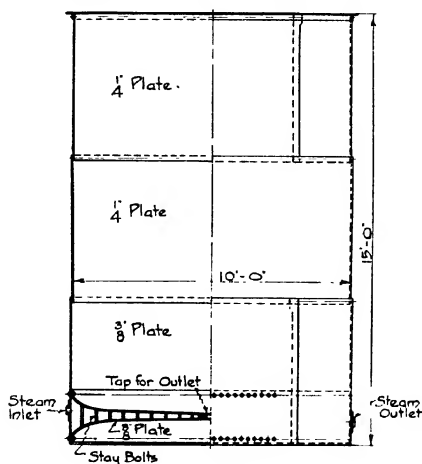


FIG. 141

Steam bottom compound tank.

Since vegetable oils decompose at comparatively low temperatures, they have but limited application. Their viscosities may be increased by air blowing. In handling vegetable oils, measures should be taken to prevent spontaneous combustion.

The plant required for compounding oils consists of tanks for the process, steam for heating, air for agitation, and the necessary transfer pumps and pipe lines. The size of batches

<sup>1</sup> For a thorough resumé of the work of various investigators, see Hamor and Padgett, "The Examination of Petroleum," pp. 354-373.

varies widely, depending upon the refinery capacity and the quantity of the various stocks produced. Compounding tanks from 100 to 1,000 barrels are in use. They are of two general types, the steam bottom type, shown in Fig. 141, and those with heater coils. Heater coils should be so designed that no steam can escape into the batch of oil. Various methods directed at

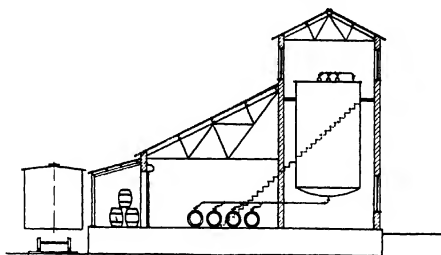


FIG. 142

Section of compound and barrel house.

the elimination of couplings or fittings inside of the tank have been used to attain this result. Welded spiral coils and box coils with each run passing through stuffing boxes on the shell of the tank and with return bends outside have been used.

A small compounding plant is shown in Fig. 142. In this case, the barrels are filled directly from the compounding tanks. This practice is quite common.

Greases are compounds of mineral oil stocks and animal fats, with soap. Compounding of this nature is done on a relatively small scale. Comparatively high temperatures are employed and mechanical stirring is usually adopted. A standard grease kettle is shown in Fig. 143.

After compounding, the various products are ready for shipment. Barrelling may be accomplished directly from the compounding tanks or the oils may be transferred to barrelling tanks.

Barrels as received from the barrel factory need no further attention than painting and stenciling. Oil barrels are used many times, however, and the returned "seconds" require careful preparation prior to refilling.

The barrels are first steamed, bung down, over drains. They are then partially filled with a weak caustic solution and rotated. The rotating is sometimes done by machine. See Fig. 144. The barrels should be allowed to drain for twenty minutes, and are then thoroughly dried by a hot air blast.



(Courtesy M. W. Kellogg Co.)

FIG. 143

Steam jacketed grease kettle

The usual heater consists of a series of steam pipes in a closed chamber, through which the air is drawn by a fan. The advisable air temperature is from 200° to 250° F. Less air is required at the higher temperature. Reports on the quantity of air used vary from 5 to 32 cubic feet per minute per barrel. Two air changes per barrel per minute or about 13 cubic feet

of fan capacity per barrel per minute is recommended. From 4 to 6 ounces of air pressure at the fan are customary.

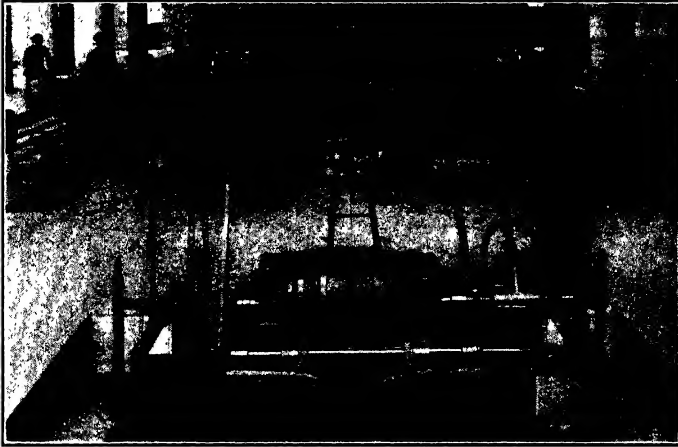


FIG. 144

Barrel preparation. Union Petroleum Company at Marcus Hook, Pa.

After the hot blast, the seconds are ready for coopering. The irregularity of this work makes it largely a matter of manual labor. Minor repairs are made, such as plugging, caulking and occasionally replacing a stave. From 16 to 20 barrels can usually be recoopered by one man in an eight hour day. Sufficient space should be reserved for this work to handle 25 per cent. of the seconds. Hoop driving capacity must be provided for the total number of barrels required. The machine used for this work, described in Chapter XIX will set up the hoops on from 65 to 70 barrels per hour.

The barrels are then ready for the gluing and draining operations. The glue coat is usually quickly set by means of a cold air blast. To conserve space, the barrels may be stacked two high as shown in Fig. 213, care being taken to preserve aisle space for handling. From four to eight hours are required for setting the glue, depending upon atmospheric condi-

tions. The air and fan requirements are about the same as those for the hot blast. A typical arrangement for preparing 1,000 barrels per day is shown in Fig. 145.

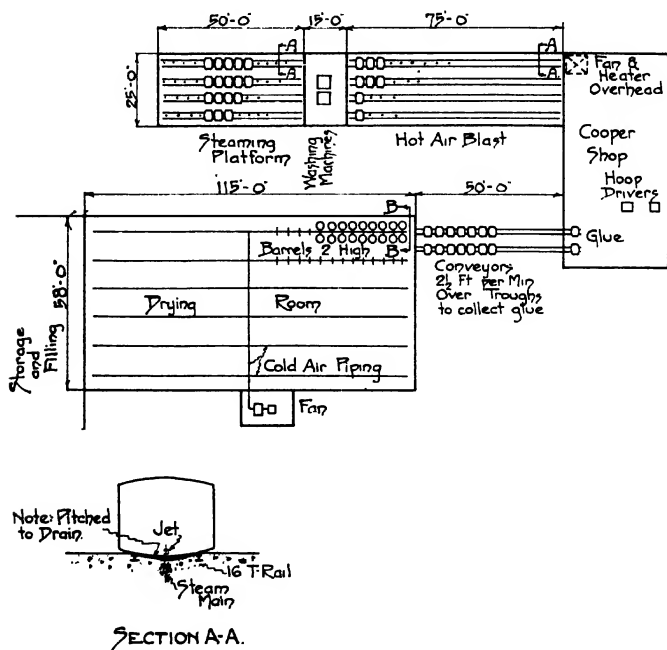


FIG. 145

Plant for preparation of wood barrels.

The barrels are now ready for painting. If the number of barrels is large, the circumferential surface may well be painted by machine. The barrels are placed between two platens and the mechanism is lowered so that the shells dip into a bath of paint. They are then revolved rapidly against the brushes, raised from the paint bath, and are conveyed to a point where the heads are painted by hand.

Filling may best be accomplished by gravity through automatic fillers of the type shown in Fig. 146. The filler shuts off

the oil when the barrel is filled. The arrangement of the filling floor will vary according to the requirements. Fig. 147 is a typical arrangement. The number of separate brands to be barrelled is a large factor. Lubricants are often barrelled from the compounding tanks, as shown in Fig. 142. The various brands are numerous and the quantity of each is usually small. The most economical layout provides for filling the barrels in rows; placing, filling and rolling them to cars or storage in successive steps. The principal consideration is to avoid any crossing or backward movement of the barrels.

The storage space reserved for full barrels is influenced by numerous factors, such as the number and volume of orders and the available shipping facilities. Requirements for different plants are widely variant. A minimum covered storage space sufficient for two days' output of filled barrels is recommended. This storage capacity will allow uninterrupted operation if shipments are held up for a day.

Can filling is usually accomplished in the department devoted to the manufacture of cases and cans. If cans and boxes are purchased, the filling may be advantageously done adjacent to the space reserved for barrel filling. Can filling may be accomplished automatically by the machine shown in Fig. 148. This machine fills 12 five gallon cans simultaneously and has a possible output of 600 cans per hour. Three men and a boy are required to operate the apparatus. After filling, the cans are packed two in a case and the loaded cases are removed by means of conveyors or hand trucks, depending upon the volume of production.

Filling stations are usually one story in height. Fireproof construction is preferable. Since there is a fire risk in the in-



FIG. 146  
Penflex automatic  
barrel filler.



terior as well as from the exterior of a filling station, exposed steel work is a source of danger. Wood block floors are recommended. Under the rolling action of heavy barrels concrete floors

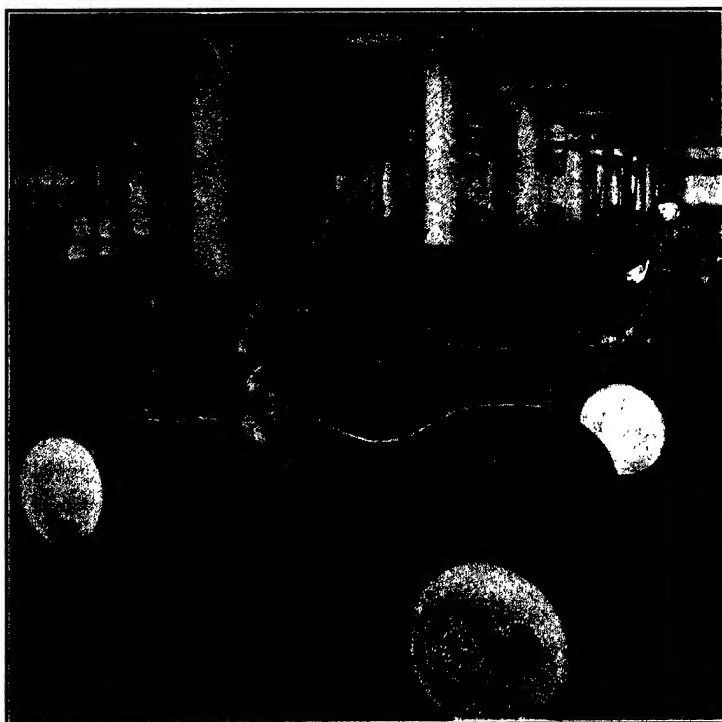


FIG. 147

Barrel-filling house, Union Petroleum Co. at Marcus Hook, Pa.

are subject to excessive wear and chipping. Moreover, the roughness of a concrete surface is liable to mar the appearance of the painted barrels. Floor loads are moderate. For a single tier of filled barrels, one high, 125 pounds per square foot should be allowed when they are placed on end, and 100 pounds per square foot when they are placed on the bilge. In filling station

work, barrels are rarely piled. This practice is more liable to be encountered in warehouses and will be discussed hereafter. When

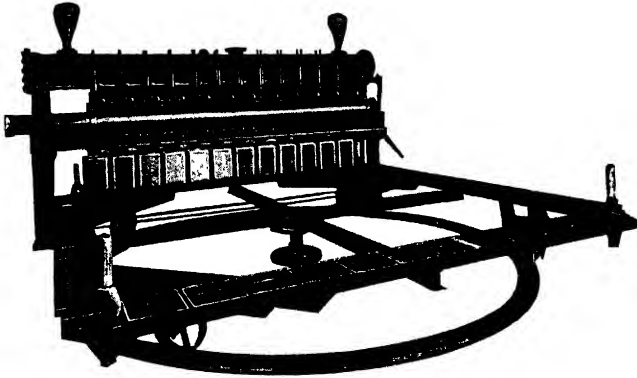


FIG. 148

Can-filling machine.

placed on the bilge, 900 square feet should be provided per hundred barrels. When placed on the end, 800 square feet will suffice. In both cases, the above figures allow for the necessary aisle space.

Warehouses for the storage of full barrels require consideration. The following remarks are applicable whether the warehouse is located at the refinery or at a distant point. Economical arrangements for handling the barrels are of primary importance. Several different brands will usually be stored, which, for convenience in inventorying and shipping, should be segregated. Barrels may be tiered two high on the bilge or on end but the labor cost is high. Modern warehouses employ barrel racks, three or four barrels high, as shown in Fig. 149, and use machines for raising and turning the barrels. The Revolvator, shown in Fig. 150, is an apparatus for doing this work.

For a warehouse with racks, 16 foot bays are recommended. The windows should be arranged to light the aisles between the racks. Multi-story warehouses are satisfactory when provided

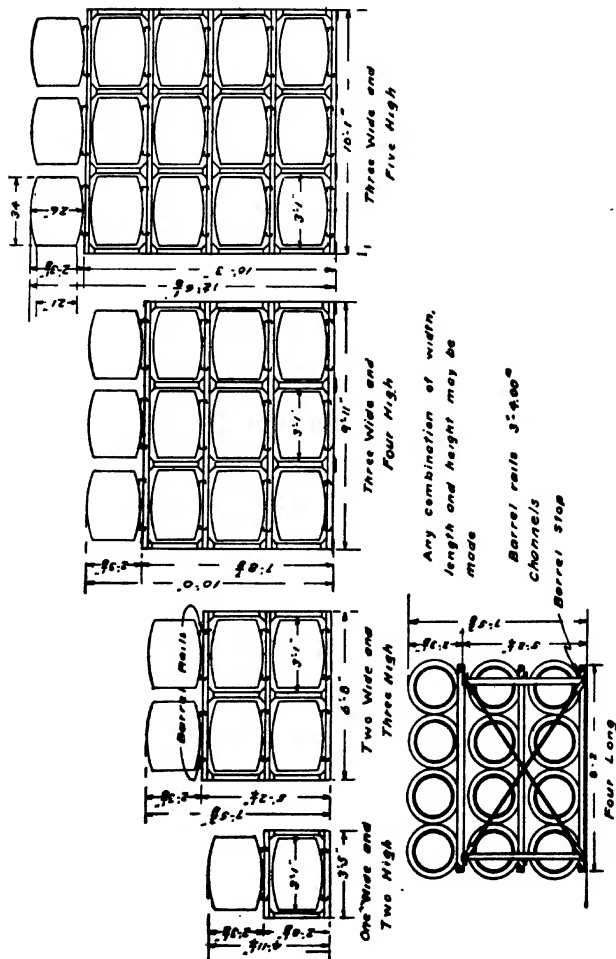


FIG. 149  
Barrel racks.

with an efficient barrel elevator system. Where land values are not excessively high, however, one story construction is considered more economical.

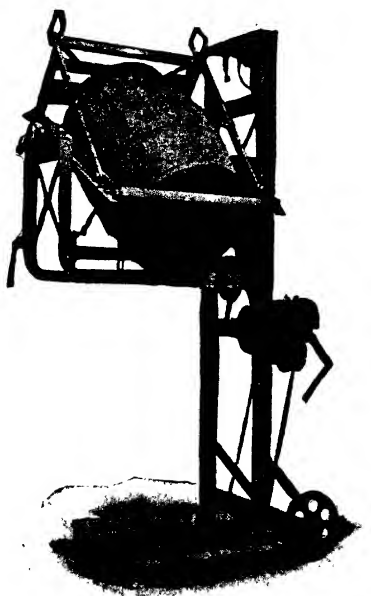


FIG. 150

Machine for raising, lowering and stacking oil barrels.

TABLE 50. FLOOR LOADS AND SPACE ALLOWANCES FOR WAREHOUSES.

	Tiers	Bilge or End Arrangement	Floor Load, Lbs. per Sq. Ft.	Space Required, Including Aisles, Sq. Ft. per 100 Bbls.
Without racks.....	2	bilge	200	500
	2	end	250	450
With racks.....	3	—	250	350
	4	—	350	260

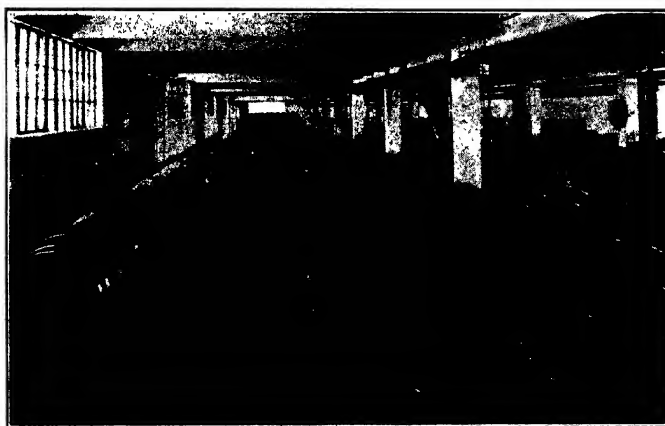


FIG. 151

Barrels awaiting shipment, Vacuum Oil Company, Bayonne, N. J.

Minimum carload requirements for filled oil barrels are about as follows:

TABLE 51

Length of Car	Loading Weight	Number of:	
		Wood Barrels	Steel Barrels
Under 36 ft. 6 in. . . . .	26,000	59	56
36 ft. 6 in. . . . .	26,780	61	58
to			
37 ft. 6 in. . . . .	27,560	62	60
to			
38 ft. 6 in. . . . .	28,340	64	61
to			
39 ft. 6 in. . . . .	29,120	66	63
to			
40 ft. 6 in. . . . .	30,420	69	66
to			
41 ft. 6 in. . . . .	31,720	72	68
to			
42 ft. 6 in. . . . .	36,920	83	80
to			
46 ft. 6 in. . . . .	42,120	95	91
to			
50 ft. 6 in. . . . .	52,000	117	112



## CHAPTER XVI

### STORAGE OF OIL

Steel tanks—Foundations—Design—Riveting—Workmanship—Details—Acid Tanks—Concrete lined reservoirs—Concrete tanks.

Petroleum and its products are usually stored in steel tanks above ground. In most locations, steel tanks are set directly on the ground. The loads are very light, rarely exceeding one and one-half tons per square foot, so that special foundations are necessary only in case of very poor soil conditions. The ground should be carefully levelled off in a circle ten feet greater than the diameter of the tank. All vegetable growth should be removed. Old refinery yards are often filled in with cinders. In such case, the cinders should be removed for a depth of at least eight inches and replaced with fine gravel, loam, or sand in order to avoid corrosion from sulphurous acids formed by moisture seeping through the cinders. Another precaution is to avoid grades requiring a combination of cut and fill, in order to prevent uneven settlement.

In some locations, piling is necessary. In such cases a sufficient number of borings should be made to ascertain the character of substrata. The number of piles, and the depth of the mat are influenced by local conditions. A common case is that of meadow land which is to be later filled in to an established yard or refinery grade. When the fill above the average high tide or ground water level exceeds eight feet, concrete piles, with a relatively thin concrete mat, is the most economical construction at present day prices. With less filling, wooden piles cut off eighteen inches above high water, and with sufficient concrete to bring the tank bottom to grade, are cheaper. If the necessary



(Courtesy Chicago Bridge & Iron Works.)

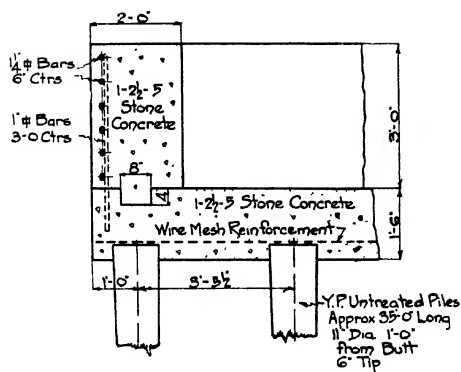
Fig. 152

66,000-barrel storage tanks, Marland Refining Co., Ponca City, Okla.

concrete mat exceeds two feet in thickness the following design has resulted in a considerable saving.

Referring to Fig. 153 it was necessary to bring the finished grade to elevation 9.5, while the pile cut-off required to keep the piles wet was at elevation 5.5. A solid mat would have been over four feet thick, resulting in excessive weight and cost. As an alternative, a mat 18 inches deep was cast, surmounted by a concrete ring two feet thick, reinforced against the outward pressure. A shallow concrete tank, three feet deep, was the result. A two-foot layer of cinders was placed inside this tank and the remaining space was filled with gravel and loam. As shown in Fig. 154, each layer was rolled by the action of the broad flat tires of the motor trucks used in conveying the materials. The surface was left about three inches above the top of the concrete ring. The tank rested entirely on the gravel and cinder filling, the inside diameter of the concrete ring exceeding that of the tank by two feet.

Foundation costs for tanks erected upon meadow land represent a large percentage of the total cost. Recent estimates (April, 1921) for foundations constructed with yellow pine piles from 35 to 40 feet long and an eighteen inch reinforced concrete mat are as follows. Twelve and one-half tons have been allowed per pile:



DETAIL OF MAT

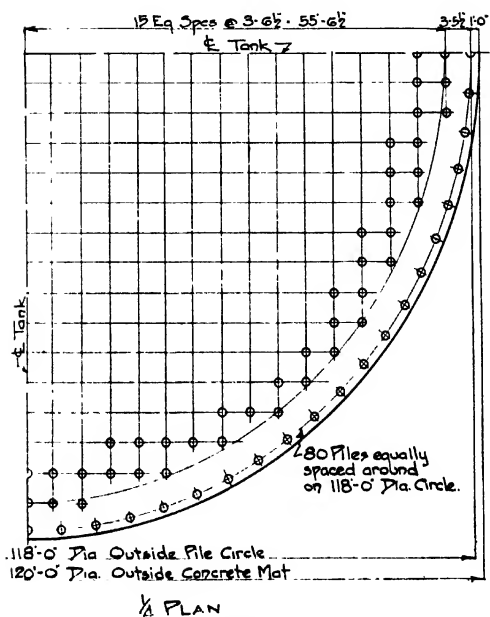


FIG. 153

Concrete and pile foundations for 65,000-barrel oil storage tank.



TABLE 52. TANK FOUNDATION COSTS

Capacity of Tank, Barrels	Cost	Cost per Barrel of Tank Capacity
80,000 .....	\$21,000	\$ .26
55,000 .....	19,000	.35
10,000 .....	4,500	.45
5,000 .....	2,400	.48
1,000 .....	800	.80
500 .....	660	1.32

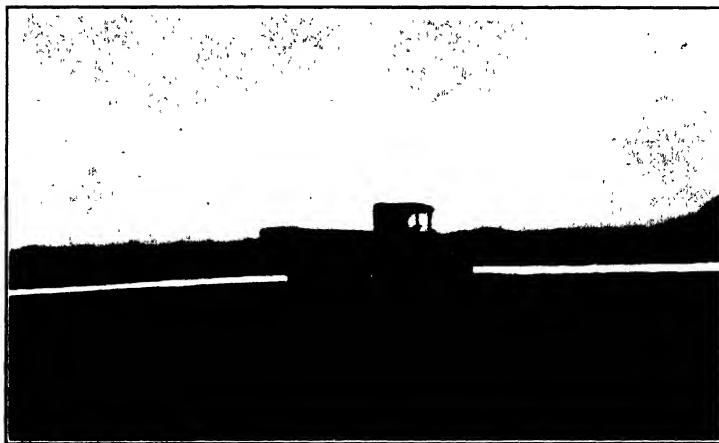


FIG 154

Placing and rolling fill for foundations of Fig. 153.

At present prices these costs add from 60 to 70 per cent. to what would otherwise be the cost of bulk storage.

Tanks are usually furnished by manufacturers in the following standard sizes:

TABLE 53. DIMENSIONS OF STANDARD TANKAGE

Nominal Capacity, (42 gal.) Barrels	Diameter, Ft.	Height, Ft.
80,000 .....	120	40
65,000 .....	115	35
55,000 .....	115	30
35,000 .....	93	30
30,000 .....	86	30
15,000 .....	66	25
10,000 .....	54	25
5,000 .....	48	25
3,000 .....	30	25
2,000 .....	25	25
1,000 .....	20	20
500 .....	20	10

These figures are subject to variation but represent average practice. Intermediate sizes are also available. Sizes of 30,000 barrels and above are more often used for field or "farm" storage, while the smaller sizes are used for refinery and terminal stocks. Typical tank specifications are given in Fig. 155.

Competition and the desire for cheap, temporary storage facilities have led to a reduction in the factor of safety far below ordinary engineering practice. Field tanks at centers of production have been built with a factor of safety as low as  $1\frac{1}{2}$ . Where the life of an oil field appears to be limited, a light tank is warranted. In the author's opinion, however, a factor of safety of two should be the minimum. Considering the number in use, it is remarkable that more failures of light tanks have not been recorded. For refinery tanks, where reasonably long life can be foreseen, a factor of safety of at least two and one-half is recommended.

The plates used are made of the lowest grade of structural steel, known to the trade as "tank steel." An ultimate tensile strength greater than 55,000 pounds per square inch cannot be depended upon. With a factor of safety of two and one-half and with joint efficiencies as later discussed, the curves shown in Fig. 156 may be used in selecting or in checking plate thicknesses for tanks of ordinary size. The curves are based upon the stresses resulting from a water content and hence provide a slightly higher factor of safety when light oil is the contained fluid.

As shown in Fig. 158, tanks are sometimes constructed with tapered rings for all plates  $\frac{3}{8}$  inch or greater in thickness. This is done to avoid "in and out" construction and "overhead" caulking and at the same time maintain the average tank diameter. The tapered rings, however, require extra labor in laying out and punching. Rectangular plates simplify shop work. Some of the more progressive manufacturers are now building tanks with all rings "straight up," each succeeding ring being placed inside the next lower one. This construction allows "down" caulking throughout and only slightly reduces the capacity of the tank.

## OIL TANKS IN BARREL CAPACITIES.

Weights include stairway outside, manhole in lower ring and in roof. Plate thicknesses are nominal only, plates being bought by weight. All plates are 72" wide except two lower courses of 80,000-barrel tank.  $\frac{1}{4}$ " plates figured at 10.2 lbs. per square foot. All seams are lap type except as noted. Horizontal seams and seams in bottom and roof are single riveted. Tanks of 31,200 barrels and larger have  $\frac{1}{4}$ " sketch plates in bottom. Roofs for tanks of 5,000 barrels or less are  $\frac{3}{8}$ " umbrella type without framing.

Capacity in Barrels 42 U.S. Gals.	Weight with Steel Roof.	Weight without Roof.	Add (to Weight with Roof) for $\frac{1}{4}$ " Roof. Deduct for Replacing Stair with Ladder.	Diameter.	Height.	Type of Roof.	Plate No. 1.			Plate No. 2.			Plate No. 3.		
							Thickness.	Number of Rows	Rivet Diameter.	Thickness.	Number of Rows	Rivet Diameter.	Thickness.	Number of Rows	Rivet Diameter.
500	11600	9100	800	17' 6"	11' 9"	Self-supporting umbrella roof	$\frac{3}{8}$ "	1	$\frac{1}{2}$ "	$\frac{3}{8}$ "	1	$\frac{1}{2}$ "	$\frac{3}{8}$ "	1	$\frac{1}{2}$ "
1000	16700	13900	1100	20' 3"	17' 6"		$\frac{3}{8}$ "	1	$\frac{1}{2}$ "	$\frac{3}{8}$ "	1	$\frac{1}{2}$ "	$\frac{3}{8}$ "	1	$\frac{1}{2}$ "
2000	26400	21600	1400	25' 0"	23' 3"		$\frac{3}{8}$ "	1	$\frac{1}{2}$ "	$\frac{3}{8}$ "	1	$\frac{1}{2}$ "	$\frac{3}{8}$ "	1	$\frac{1}{2}$ "
2500	30600	24700	1400	27' 9"	23' 3"		$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
3000	34600	27500	1400	30' 6"	23' 3"	Self-supporting umbrella roof	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
4000	41100	33600	1800	31' 6"	29' 0"		$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
5000	47500	38200	1800	33' 11"	29' 0"		$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
7500	64300	50300	3000	43' 0"	29' 0"	No. 10 Roof plates center col. with trusses and radial rafters.	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
10000	81100	62400	4000	49' 8"	29' 0"		$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
12500	100200	75300	5000	55' 9"	29' 0"	No. 10 Roof plates center col. with trusses and radial rafters.	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
15000	116500	87300	6000	61' 0"	29' 0"		$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
20000	152000	111300	8000	70' 2"	29' 0"		$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
25000	178600	129400	10000	78' 9"	29' 0"		$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
31200	230500	164300	12500	87' 8"	29' 0"	No. 10 Roof plates series of columns with beams and rafters.	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
35000	254000	181000	14000	93' 7"	29' 0"		$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
37500	270300	194700	15000	96' 6"	29' 0"		$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
40000	294000	212000	18000	99' 5"	29' 1"	No. 10 Roof plates series of columns with beams and rafters.	$\frac{3}{8}$ "	4	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
45000	323000	232000	18000	105' 3"	29' 1"		$\frac{3}{8}$ "	4	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
50000	358000	256000	20000	111' 1"	29' 1"		$\frac{3}{8}$ "	4	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
55000	383600	273000	22200	117' 0"	29' 1"		$\frac{3}{8}$ "	4	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	4	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "	$\frac{3}{8}$ "	2	$\frac{1}{2}$ "
66000	443500	327500	22200	117' 1"	34' 10"	No. 10 Roof plates series of columns with beams and rafters.	$\frac{3}{8}$ "	†	$\frac{1}{2}$ "	$\frac{3}{8}$ "	4	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "
77000	515000	392000	22200	117' 2"	40' 7"		$\frac{3}{8}$ "	†	$\frac{1}{2}$ "	$\frac{3}{8}$ "	4	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "
80000	529000	406000	22200	117' 2"	41' 10"		$\frac{3}{8}$ "	†	$\frac{1}{2}$ "	$\frac{3}{8}$ "	4	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	†	$\frac{1}{2}$ "	$\frac{3}{8}$ "	4	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "
							$\frac{3}{8}$ "	†	$\frac{1}{2}$ "	$\frac{3}{8}$ "	4	$\frac{1}{2}$ "	$\frac{3}{8}$ "	3	$\frac{1}{2}$ "

† Represents Butt Joint.

Tanks from 7,500 bbls. to 31,200 bbls. inclusive have conical roofs supported by center column and trussed rafters. Larger tanks have roofs supported by a series of columns with beams and rafters.

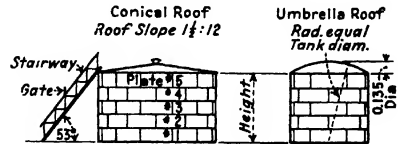


Plate No. 4.			Plate No. 5.			Additional Plates.			Bottom Plates.	Bottom Angle.	Top Angle.	No. of Plates Around.	Approximate Plate Length.
<i>t</i>	Rows.	Diameter.	<i>t</i>	Rows.	Diameter.	<i>t</i>	Rows.	Diameter.					
$\frac{1}{16}$	1	$\frac{1}{16}$							$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 2 \times \frac{1}{2}$	3	18' 7"
$\frac{1}{16}$	1	$\frac{1}{16}$							$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 2 \times \frac{1}{2}$	4	16' 0"
$\frac{1}{16}$	1	$\frac{1}{16}$							$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	5	15' 11"
$\frac{1}{16}$	1	$\frac{1}{16}$							$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	5	17' 8"
$\frac{1}{16}$	1	$\frac{1}{16}$	$\frac{1}{16}$	1	$\frac{1}{16}$				$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	6	16' 3"
$\frac{1}{16}$	1	$\frac{1}{16}$	$\frac{1}{16}$	1	$\frac{1}{16}$				$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	6	16' 9"
$\frac{1}{16}$	1	$\frac{1}{16}$	$\frac{1}{16}$	1	$\frac{1}{16}$				$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	6	18' 9"
$\frac{1}{16}$	1	$\frac{1}{16}$	$\frac{1}{16}$	1	$\frac{1}{16}$				$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	8	17' 3"
$\frac{1}{16}$	1	$\frac{1}{16}$	$\frac{1}{16}$	1	$\frac{1}{16}$				$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	9	17' 9"
$\frac{1}{16}$	2	$\frac{1}{16}$	$\frac{1}{16}$	1	$\frac{1}{16}$				$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	10	18' 0"
$\frac{1}{16}$	2	$\frac{1}{16}$	$\frac{1}{16}$	1	$\frac{1}{16}$				$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	11	17' 11"
$\frac{1}{16}$	2	$\frac{1}{16}$	$\frac{1}{16}$	1	$\frac{1}{16}$				$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	12	19' 0"
$\frac{1}{16}$	2	$\frac{1}{16}$	$\frac{1}{16}$	1	$\frac{1}{16}$				$\frac{1}{16}$	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	14	18' 3"
*	2	$\frac{1}{16}$	*	1	$\frac{1}{16}$				* sk.	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	15	19' 0"
*	2	$\frac{1}{16}$	*	1	$\frac{1}{16}$				* sk.	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	16	19' 2"
1	2	$\frac{1}{16}$	*	*	$\frac{1}{16}$				* sk.	$3 \times 3 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	18	17' 7"
1	2	$\frac{1}{16}$	*	1	$\frac{1}{16}$				* sk.	$4 \times 4 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	17	19' 2"
1	2	$\frac{1}{16}$	*	1	$\frac{1}{16}$				* sk.	$4 \times 4 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	18	19' 2"
1	2	$\frac{1}{16}$	*	2	$\frac{1}{16}$				* sk.	$4 \times 4 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	19	19' 2"
1	2	$\frac{1}{16}$	*	2	$\frac{1}{16}$				* sk.	$4 \times 4 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	20	19' 2"
$\frac{1}{16}$	3	$\frac{1}{16}$	$\frac{1}{16}$	2	$\frac{1}{16}$				* sk.	$4 \times 4 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	20	19' 2"
$\frac{1}{16}$	3	$\frac{1}{16}$	$\frac{1}{16}$	3	$\frac{1}{16}$				* sk.	$4 \times 4 \times \frac{1}{2}$	$3 \times 3 \times \frac{1}{2}$	20	19' 2"

Courtesy Chicago Bridge and Iron Works.

Fig. 155.

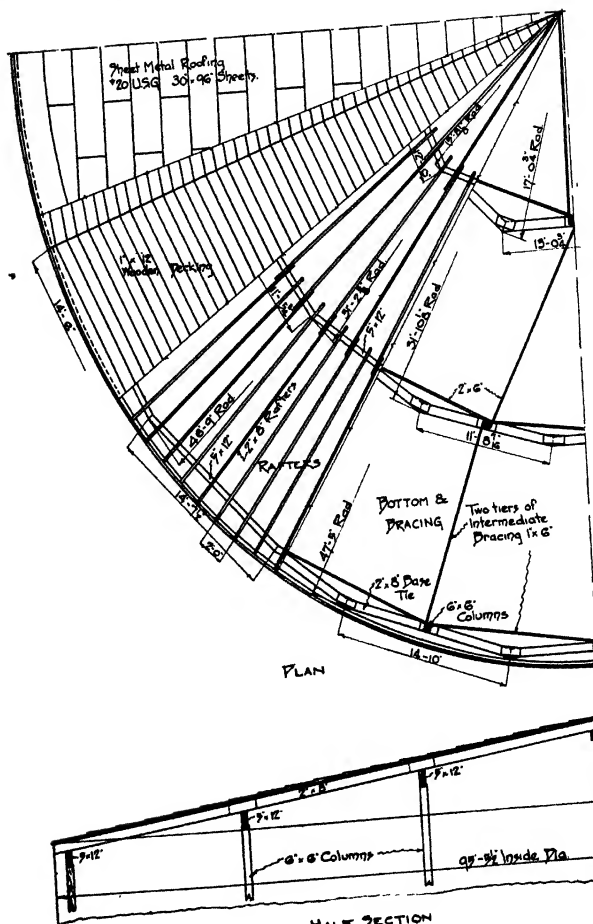
\* Represents No. 6 U. S. S. M. Gauge.



Corrosion in oil tanks occurs at three points, the bottom, the top ring, and the roof. The bottom is affected by the humus acids in the soil. The top ring, at and near the usual oil level, is subject to the action of the vapors and of possible condensed moisture. The roof corrodes for the same reason. In order to combat these conditions, it is often advisable to use heavier metal. Manufacturers' standards usually call for a bottom thickness of  $\frac{1}{4}$  inch on the larger sizes of tanks and  $\frac{3}{16}$  inch for smaller tanks. This is sufficient to provide strength and tightness, but does not allow for corrosion. In erecting a number of 55,000 barrel tanks one prominent company called for a bottom thickness of  $\frac{3}{8}$  inch. In the case above mentioned the increased weight amounted to 43,000 pounds and entailed an additional cost of \$1,600.00 per tank at prices then prevailing. This amount was considered good insurance against future trouble. Although less metal will often provide sufficient strength, a minimum shell thickness of  $\frac{1}{4}$  inch is recommended. Corrosion in the roof is largely a question of protective paint. The question of increased weight as a safeguard against damage from corrosion is one to be determined for the individual case. For temporary field storage at centers of production, it is not advisable. For refineries and terminals of long anticipated life, however, it should receive consideration.

Wood-roofed tanks are and will undoubtedly continue to be used to some extent for tank farm storage of crude oil. Fig. 157 shows a typical wooden roof for a large field tank. A twenty-gauge sheet iron surface is nailed over the roof boards. The roof is constructed independently of the tank shell and therefore lends no stiffness to the shell. Cases are on record where the shells of empty wood-roofed tanks have been blown in by external wind pressure. Such roofs cannot be made gas tight. They also increase the fire risk. Insurance premiums on a wood-roofed tank are about seventy-five per cent. more than on an all steel tank.

The evaporation loss in the wood-roofed type is undoubtedly higher than in the properly vented gas-tight tank. Exact figures



HALF SECTION  
FIG. 157

Wood roof for 35,000-barrel storage tank.

for comparison are difficult to obtain and are usually of little value on account of the differences in gravity and freshness of the oils. Tests have shown the evaporation in wood-roofed tanks to vary from six times as great to about the same as that in all steel tanks. The average is probably well over double. For these reasons, except where the small difference in cost is vital, wood roofs are not recommended.

One method of bracing a wood-roofed tank employs the so-called "sand-line" construction. At two or three different heights, preferably 10 and 20 feet from the bottom and immediately below the roof framing timbers, four  $\frac{5}{8}$  inch cables are strung across the tank diametrically, dividing the area into eight 45 degree segments. These cables are attached to the shell with clip angles, and are attached at the center to a forged steel ring surrounding the center post. Turnbuckles are applied to the cables in order to provide uniform tension.

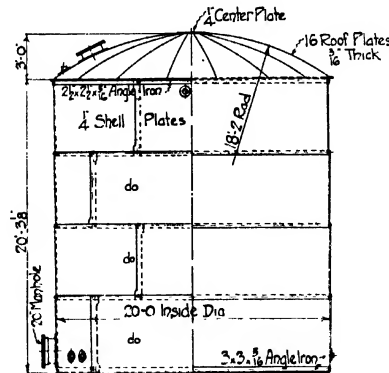


FIG. 158

1,000 barrel, globe roof oil storage tank.

The all steel roof is greatly favored in present-day construction. Rolled steel shapes are used for the structural framing. For gas tight roofs the roof metal proper is usually No. 10 U.S.S.M. gauge, or  $\frac{3}{16}$  inch. For roofs not caulked,  $\frac{1}{8}$  inch has been used. Formerly it was general practice to use plates of



segmental shape with the seams radiating from the center. This resulted in some waste in shearing plates. During the recent period of high steel prices rectangular plates have been used, cutting a V wedge along the half diameter seam to allow the roof to be assembled as a cone. While saving material, this layout entails greater difficulty in matching plates and consequently increases erection costs. This objection may be overcome by leaving sufficient metal at the circumference to overhang the top angle irons. The overhanging portion of the plates is trimmed in the field with a cutting torch or chipping hammer to fit the tank circumference, and the circumferential rivet holes are then made with a screw punch.

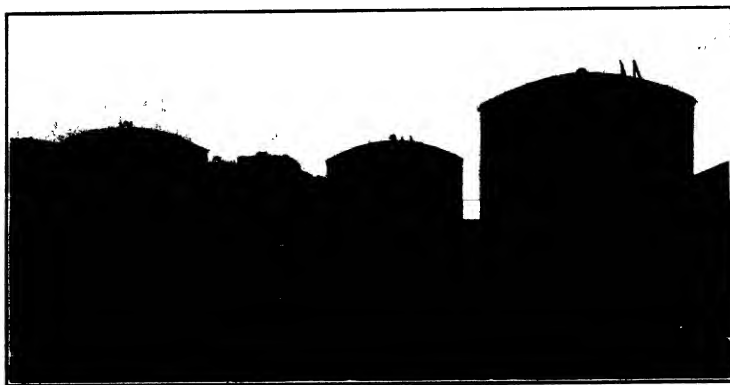


FIG. 159

Globe roof stock tanks. Chalmette Oil and Refining Co., Chalmette, La.

For tanks up to 54 feet in diameter the self-supporting globe roof is satisfactory and presents a pleasing appearance. For sizes over 30 feet in diameter, however, it is more expensive than the cone type supported on rafters. A self-supporting globe roof is made up of segmental plates. Three-sixteenths inch metal is satisfactory. The larger sizes require a center post, which is usually made of standard steel pipe. The radius of the roof is made equal to the tank diameter. Globe roofs are shown in Figs. 158 and 159.

Gas tight roofs are to be preferred from the standpoint of fire risk. All openings except vents should be provided with covers which are either closely fitted or are furnished with proper gaskets. The vents should be protected with brass or monel metal wire cloth of not less than 50 meshes per inch. If roofs are thus constructed gas tight, the need for the use of explosion hatches is to be questioned. Direct strokes of lightning are not, as popularly supposed, the usual cause of tank fires. Such fires are more commonly due rather to the gases escaping and becoming ignited by static electricity which is present during a time of thunder storm, and which often ignites the escaping gases causing a flash-back to the contents of the tank. Since explosion hatches represent a further potential gas leak which cannot be properly screened, it would seem safer to depend upon regular vents which can be protected by the wire cloth. This subject is further discussed in the chapter on Fire Protection.

The question of tank riveting deserves attention. The standard joints for water and steam are not applicable with success when the vessel contains petroleum or its products, particularly the lighter ones. The two factors to be considered are the efficiency of the joint and its oil tightness. Since the oil tight joint is rarely the most efficient, a compromise must usually be effected. When caulking the edges of plates, it is apparent that if the rivets are spaced too far apart the plate being caulked may spring away from the under plate between rivets. This distance may vary for different liquids, but for oil the maximum is fairly well established. The distance from edge to edge of rivet holes should be not over 6 or 7 times the plate thickness. It should be noted that the distance in question is not that from center to center of rivets but the clear space left between two adjacent rivet holes.

Table 54 has been prepared from this standpoint as well as from that of reasonable joint efficiency:

TABLE 54. TANK RIVETING

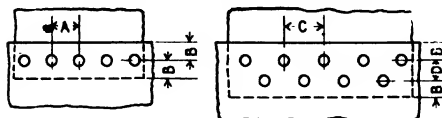


Plate	Rivet	A	B	C	D	Efficiency, Per Cent.	
(Dimensions in Inches)						Single	Double
$\frac{1}{4}$	$\frac{5}{8}$	$2\frac{1}{2}$	$1\frac{1}{8}$	$2\frac{1}{2}$	$1\frac{3}{4}$	40	72
$\frac{3}{8}$	$\frac{3}{4}$	$2\frac{1}{2}$	$1\frac{1}{8}$	$2\frac{1}{2}$	$2\frac{1}{4}$	41	73
$\frac{1}{2}$	$\frac{7}{8}$	—	$1\frac{1}{4}$	$2\frac{1}{2}$	2	43	63
$\frac{3}{4}$	$1\frac{1}{8}$	—	$1\frac{1}{2}$	$3\frac{1}{4}$	$2\frac{1}{2}$	—	62
$1\frac{1}{2}$	1"	—	$1\frac{3}{4}$	$3\frac{3}{4}$	3	—	61

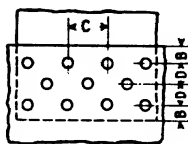


Plate	Rivet	B	C	D	Efficiency, Per Cent
$\frac{1}{4}$	1"	$1\frac{1}{2}$	4	3	75
$\frac{3}{8}$	1"	$1\frac{3}{4}$	4	3	75
$\frac{1}{2}$	1"	$1\frac{1}{4}$	$3\frac{3}{4}$	3	73

This table is based upon 55,000 pounds per square inch, ultimate tensile strength of plate, 40,000 pounds per square inch shearing value of rivets, and 80,000 pounds per square inch bearing value of plate.

In order to reduce costs, cold riveting is occasionally resorted to. It is to be recommended for rivets under one-half inch in diameter where the high joint efficiency of hot rivets is not required. Roofs and the top rings of large tanks may well be cold riveted. For smaller tanks, where extra plate thickness is provided, to insure adequate working strength and provide against corrosion, cold riveting may be applied to all rings.

The following designs for cold driven joints are recommended.

TABLE 55. COLD RIVETED JOINTS

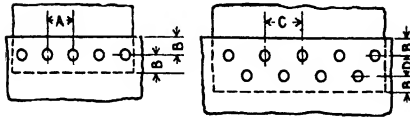


Plate	Rivet	A	B	C	D	Efficiency, Per Cent.	
		(Dimensions in Inches)				Single	Double
$\frac{1}{4}$	$\frac{7}{8}$ "	$1\frac{1}{2}$	$\frac{3}{4}$	2	$1\frac{3}{4}$	29	42
$\frac{3}{8}$	$\frac{7}{8}$ "	$1\frac{1}{4}$	$\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{1}{8}$	34	53
$\frac{1}{2}$	$\frac{7}{8}$ "	1	$\frac{1}{2}$	—	—	29	—

Many tanks are also made with cold driven bottom rivets. Since the bottom of a tank should receive the best possible workmanship, the economy of this practice is questionable. In cold riveting, the heads are not so well formed as in driving hot rivets. Loose rivets are consequently more liable to develop. The obvious difficulties of repairing tank bottoms would seem to warrant the slight extra expense of a well driven hot job.

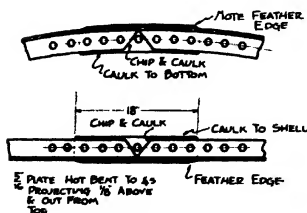
There is a popular prejudice in the oil business against the use of chain riveting and in favor of staggered joints. As a matter of fact, there seems to be no logical reason for this prejudice. Moreover, some shops have their multiple punches so arranged that more economical shop work can be obtained by using chain riveting. Criticism is usually directed at the tightness of the joint. A study of a chain joint shows that the clear distance between the rivet holes along the caulking edge is usually less than in the staggered construction. Since the tightness depends on this distance, the chain type should receive no discrimination.

Improper scarfing or thinning down of the corner of the middle plate where three plates in the assembly come together is a frequent source of trouble. Plates over one-quarter inch in thickness should be scarfed hot, the metal being drawn down to a fine edge not more than  $\frac{1}{16}$  inch thick. Plates  $\frac{1}{4}$  inch and less in thickness may be scarfed cold. Power hammers are often used for this purpose.

Tank details deserve careful consideration. Several of the

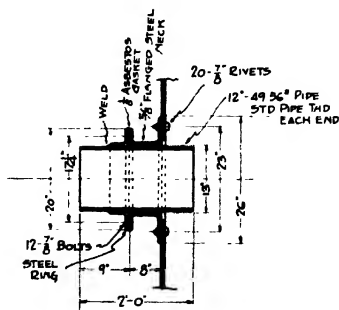
more important points are discussed below. The joint between the bottom angles is one of the most difficult to make tight. A shoe of bent plate is introduced back of the angle and between the bottom and shell plates. While various plate thicknesses have been used, one-quarter inch is recommended. The shoe should fit the angle closely and the ends of same should be drawn down to a thin edge. The angle is caulked to the bottom and over the shoe. If the angles are cut square the joint between them is split caulked; if cut V-shaped as shown in Fig. 160 it is caulked around the V to the shoe; and in both cases the shell leg is caulked past the shoe a distance of at least twelve inches. The better practice is to bevel and caulk the vertical leg of the angle to the shell around the entire circumference. The shoe is then caulked to the bottom and to the shell, assuring a tight joint.

For large pipe connections, a construction similar to that shown in Fig. 161 is recommended. It will be noted that there



BOTTOM ANGLE SPLICE

FIG. 160



12\"/&gt;

FIG. 161

Detail of splice for bottom angle. Tank nipple for large pipe connections.

are no threads to leak. For smaller connections, forged steel flanges with a square heel are desirable. They should be caulked to the shell around the circumference, and the shell should be chipped and caulked to the flange. Where the pipe extends through the shell, a double hub flange caulked as above, and

●



## Steel tank stairs.

the windlasses, gauge nipple and manhole.

4

placed diametrically opposite on the first ring are recommended in place of a single manhole, for tanks 75 feet or more in diameter. Convenience in cleaning tank bottoms will more than pay the extra cost. The roof manholes should be placed approximately above those on the shell.



FIG. 163

Steel tank stairway of trussed design.  
Courtesy Chicago Bridge & Iron Works.

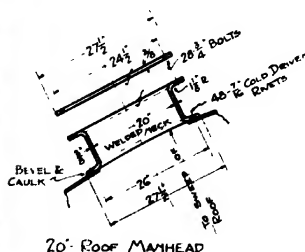
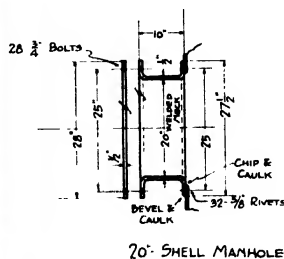


FIG. 164

Tank manholes.

Swing pipes are attached to a swing joint immediately inside the shell. Two extra heavy elbows with a nipple between them have been used with success as a substitute for the swing joint. In order to reduce the weight of the swing pipe in the larger sizes, casing has often been substituted for the standard pipe.

A gauge nipple, economical and sufficiently gas tight for ordinary purposes, is shown in Fig. 165. Where greater assurance of tightness is desired, the form shown in Fig. 166 may be used. On large field storage tanks, four gauge nipples should

be used, placed from two to three feet from the circumference and 90 degrees apart. Care should be taken that there are no obstructions such as rafters or swing-pipes in a plumb line below the nipple.

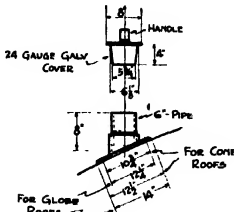


FIG. 165

Gauge nipple.

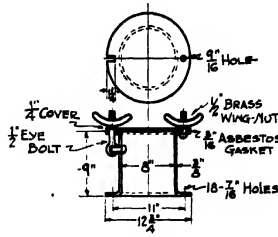


FIG. 166

An economical and satisfactory gas vent is shown in Fig. 167. Field tanks of 30,000 barrels' capacity or larger should have five of these vents arranged as shown in Fig. 168. For the smaller tanks, one vent at the apex of the roof is generally considered sufficient.

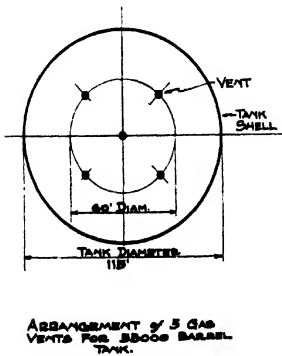


FIG. 167

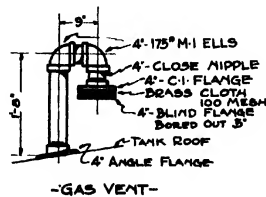


FIG. 168

In erecting a tank, the bottom is laid and riveted and caulked on trestles or on horses about 30 inches high. The first ring



is also assembled and driven while the bottom remains elevated. Before lowering, it is customary to test the bottom under six or eight inches of water. The tank is then raised on jacks around the circumference, all horses and debris removed from underneath, and the bottom gradually lowered to grade. Fig. 169 shows a tank bottom under construction.

Two systems of scaffolding are in use for assembling, riveting and caulking the shell. Where water is available, floating scaffolds are used to some extent, the water being pumped into the tank as fast as the shell is caulked tight. This method has the advantage of testing the tank as the work proceeds. In other cases, holes are punched in the sheets to receive bolted brackets upon which the scaffolding plank rests. As the scaffolding is removed these holes are plugged with hot rivets.

The usual precautions for steel erection in the matter of blind holes, drifting, quality of rivets, and general workmanship



FIG. 169

Tank bottom assembled on "horses" prior to lowering to grade.

should be observed. In addition, particular attention should be paid to the shoes at the bottom angles, to intersections of three plates, and to the caulking of the fittings to the shell and of the shell to the fittings. These points are most susceptible to leakage. At points where three plates meet, it is good practice to heat the metal cherry red after the plates are bolted in position, and thoroughly to "lay" the joint up with sledges prior to riveting. Oil burning torches are used for this purpose.

Every tank should be tested with water prior to painting. While the water test is necessary, it will not always guarantee absolute oil tightness, especially with light products. It will indicate the important leaks, however, and any slight leakage may usually be taken up at a later date.

Small tanks up to 500 barrels' capacity are often made in the horizontal type. The largest size which can be transported assembled is  $10 \times 40$  feet, having a nominal capacity of 560 barrels. Horizontal tanks should have longitudinal seams double riveted even if the theoretical stresses do not require it. The double riveting adds stiffness.

Acid tanks require special consideration. The usual acids encountered are fuming, strong ( $66^{\circ}$  B.), and weak sulphuric acid. For fuming and strong acids no problems are encountered further than a liberal factor of safety. On account of possible corrosion, the author recommends a minimum plate thickness of  $\frac{3}{8}$  inch. For small capacities, horizontal tanks placed on masonry piers are commonly used. For larger capacities the standard vertical tank dimensions may be followed. Weak acid is very corrosive, however, and requires a lead lined tank. Rivets are driven with flat heads from  $\frac{1}{16}$  to  $\frac{1}{8}$  inch high inside. It is customary to leave out occasional rivets so that possible leaks developing in the lining may be easily located. The shell plates need not be bevelled or caulked. Chemical lead weighing 8 pounds per square foot, or lead with 6 per cent. antimony at  $7\frac{1}{2}$  pounds per square foot is ordinarily used for lining. The lead is dressed for support around the top angle of the tank and is held to the shell by lead straps. These straps should be spaced at not less than eight foot intervals around the circumference of the shell. Round edge tire iron is excellent for the straps as the round edges will not cut the lead during dressing. This prevents possible future leaks. The straps are bolted to the shell with half-inch bolts. The heads are countersunk inside. In order to protect the otherwise exposed steel strap and bolts, a narrow sheet of lead over the lead straps is burned to the lining proper. Fig. 170 shows the details and bill of material

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for a lead lining for a vertical tank 15 feet in diameter by 10 feet high.

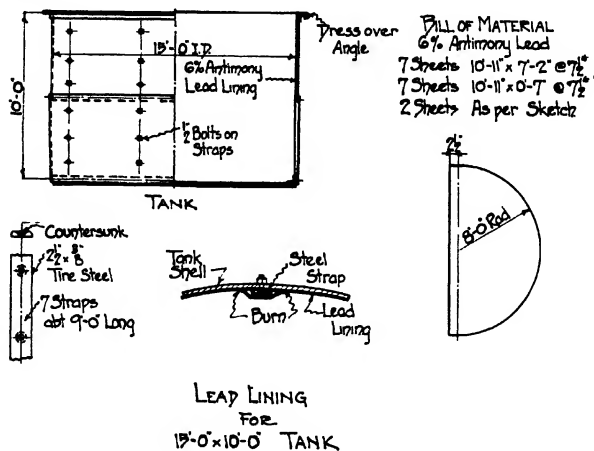


FIG. 170

Where the topography of the ground is favorable and the expense is warranted, it is advisable to elevate all acid tanks so that the bottom is open to inspection. Concrete piers with steel I-beams are recommended. Since the concrete is attacked by the acid and fumes, however, a suitable protective covering is essential. Coal tar and high melting point petroleum pitch have been used with success.

Water tops, Fig. 171, are used to some extent on small refinery tanks containing light products. In one case, as a result of using the water top, tests have shown an average reduction in the annual evaporation from 14.7 to 1.32 per cent. This is a remarkable record. Sprinklers on the roofs of tanks containing light products are also used with success. Fig. 172 shows this device. The revolving spray keeps the roof wet and cool and the water dropping down from the roof also aids by keeping the shell cool.

After testing the bottom and before lowering to grade, the metal should receive a protective coating. Ship bottom paint or a heavy asphalt paint are recommended. One company uses

hot asphalt applied with long handled brushes. The shell and roof, after testing, should receive at least two coats of good metal protecting paint. Red lead ground in pure boiled linseed oil



(Courtesy Hammond Iron Works.)

FIG. 171

Water top for storage tank being erected.

makes an excellent preservative. It is open to criticism because of its heat absorbing qualities. Theoretically, white would be the best color. It soon becomes weathered, however, and for all practical purposes a light gray is acceptable. Three coats are recommended, one of red lead and two of first quality gray graphite paint. If only two coats are used, it is difficult to ob-

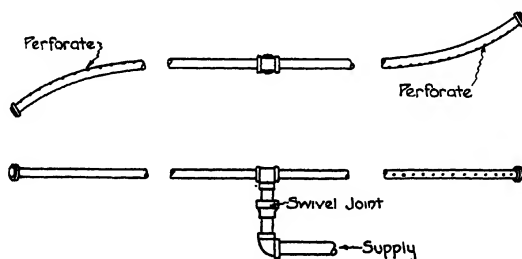


FIG. 172

Water spray for tank cooling.

tain a pleasing appearance with one coat of gray over the red lead. Two coats of light gray are recommended in this case. Since rain splashing from the ground will disfigure the first ring, some companies paint this ring black.

All the precautions should be observed which are usually taken in painting any first class structural or plate work, such as removing all mill scale and rust with wire brushes, spreading uniformly and working the paint out well with brushes, etc.

The cost of tanks varies with the capacity. The curve shown in Fig. 173 shows the cost per barrel exclusive of foundations for tanks of various sizes erected at prices prevailing in 1916 within 500 miles of Pittsburgh. In the selection of tanks to provide a given total capacity, the larger sizes are more economical than several smaller units.

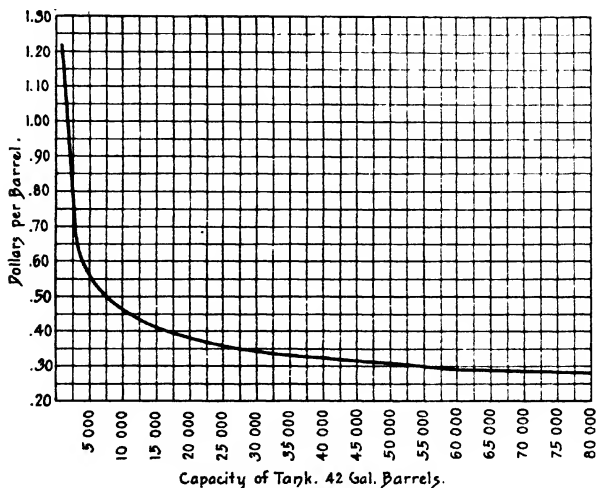


FIG. 173

Relation of price per barrel to size of tank, costs as of 1916.

Oil is occasionally stored in earth reservoirs. This practice is wasteful on account of seepage and evaporation and is only used in emergencies, such as occur when opening a new pool.

Concrete lined reservoirs are in successful use on the Pacific coast for the storage of heavy oil. Sizes are on record up to 525 feet in diameter, holding 750,000 barrels. The material excavated for the bottom is used as a dike to increase the depth.

After thoroughly rolling and tamping the earth work, a concrete lining, usually 3 inches thick, is poured. A dense concrete is desirable, although a mixture as lean as one part cement to 7 parts of combined fine and coarse aggregate has been used. Tests of the available materials should be made to determine the suitable proportions. The slab lining is reinforced with expanded metal or wire mesh. Expansion joints have proved troublesome. It is more economical in the long run to eliminate them, relying on sufficient reinforcement to take up temperature stresses.

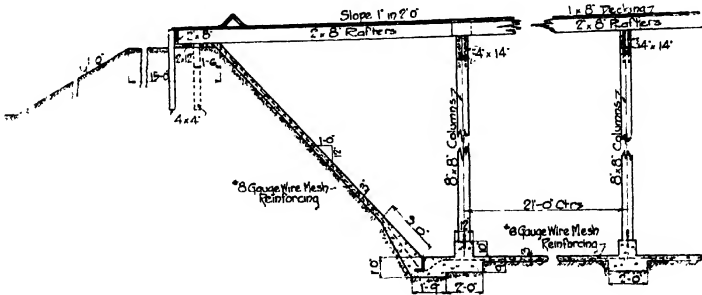


FIG. 174

Section of concrete-lined oil reservoir with wood roof.

In addition to the usual precautions taken to insure first class workmanship on concrete, the preparation of the bottom, slopes and the junction of slopes and bottom should have close supervision.

Roofs are constructed of reinforced concrete or of wood with a tar and gravel surface on timber framing.

Fig. 174 shows a 750,000 barrel concrete lined reservoir with a timber roof. The cost is considerably under that of steel tanks. Pre-war figures are from 11 cents to 13 cents per barrel for reservoirs with wooden roofs, and from 28 cents to 30 cents per barrel for those with concrete roofs. Bulletin No. 155 of the Bureau of Mines gives valuable information on concrete lined reservoirs.

Reinforced concrete tanks have also been used for ordinary storage conditions. For light oils, such as gasoline, kerosene, and gas oil, results have been disappointing. For heavy crudes and residuals some success has been attained.

The most notable installation consists of eleven tanks erected at Everett, Mass., having an approximate capacity of 80,000 barrels each. These tanks are 150 by 130 feet in plan and 25 feet deep. They are built partly in a cut. The portion above ground is buttressed by an earth shoulder. There is a space between the tanks of only 2 inches, which is filled with hair felt. No special temperature reinforcing was provided. It was assumed that once the tanks were filled and covered, there would be little temperature change. Results have apparently justified the assumption. The mixture was about one part of cement, 2.1 parts of sand, and 3.58 parts of stone, to which was added powdered diatomaceous earth or "Celite" in the proportion of 2 pounds per bag of cement used. The Celite aided in filling the pores of the concrete. Fig. 175 shows the above tanks under construction. In storing Mexican crude oil the owners report excellent results. Since this installation was made within municipal fire limits, tanks either buried or excessively diked were necessary. The cost was higher than that of steel tanks of equal capacity.

Two tanks constructed on the eastern coast for the storage of fuel oil were not as successful. They are 100 feet square in plan and 21 feet deep. Seepage in this case is reported as high as 10,000 gallons per day. Under drains and centrifugal pumps were installed to catch this oil. The loss was thereby materially reduced.

Cylindrical tanks 117 feet in diameter by 30 feet high have been built for the government in the Panama Canal Zone. The "Panama Canal Record" reports upon the success and economy of this installation in the issue of September 22, 1920.

Generally speaking, the use of concrete has met with little success except in the case of linings for earth reservoirs (which must not be confused with structurally independent tanks). Porosity and uncertainty of workmanship are the principal draw-

backs. The cost of concrete, except under very favorable conditions, is higher than that of standard steel tanks, and the time required for erection is longer. Concrete possesses the advantage of much better insulating properties than steel and under stringent fire regulations and high land costs its use is occasionally economical.

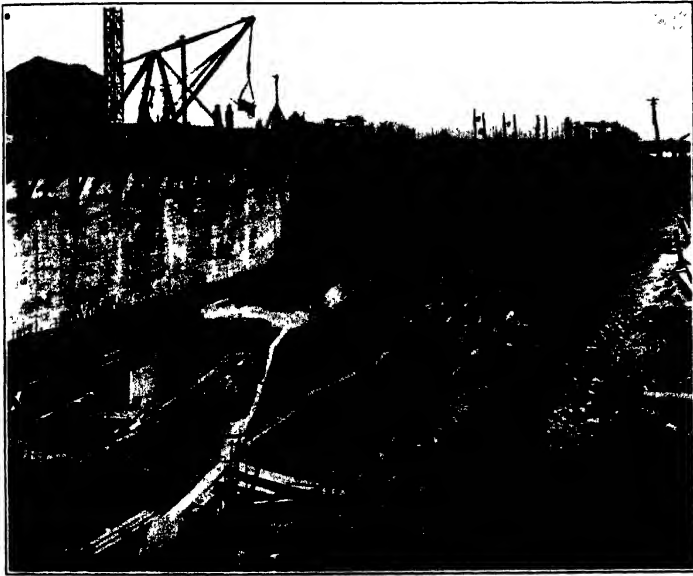


FIG. 175

Oil storage tanks of reinforced concrete being constructed by the Leonard Engineering Co. for the Beacon Oil Co., at their Everett refinery.

Many oils, especially those stored in steel tanks above ground, have to be heated before they can be successfully pumped. The principles involving the computation of heat input and radiation are quite simple. Unfortunately, however, they rarely cover the extreme and unexpected case. A fire, a quick delivery to a boat, or some other unexpected situation, may require the oil to be heated ready for pumping in the shortest possible time.



The savings which may be realized from the ability to meet such an emergency will warrant the installation of heating apparatus of much greater capacity than may appear theoretically to be sufficient.

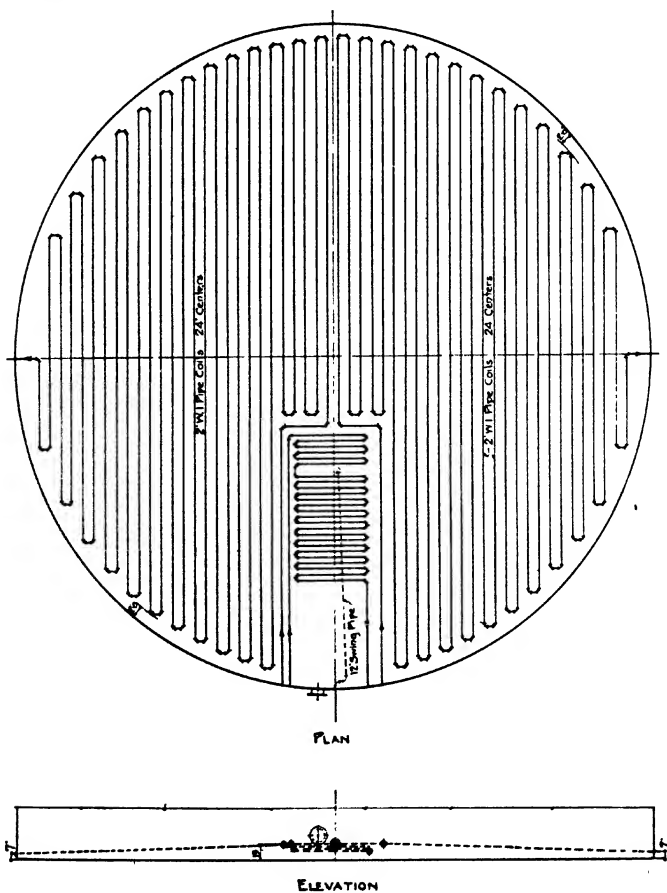


FIG. 176

Heater coils for large oil storage tank.

The following table based upon the use of steam at 100 pounds pressure will serve as a safe guide for tanks located in the

northern states in determining the heating surface required per barrel for oils of various cold tests.

Cold Test °F.	Square Feet per 1000 Barrels.
50 .....	25
70 .....	34
90 .....	43

These figures may be modified for use in southern latitudes.

Box coils made of 2 inch pipe are satisfactory. The pipes should be given sufficient slope for proper drainage. Fig. 176 shows the arrangement of coils for a 65,000 barrel tank. The piping is divided into two main coils, with a third auxiliary coil placed beneath the swing type. After the oil is heated, this auxiliary coil will provide sufficient heat to discharge the tank at a nominal rate. In an emergency, all three coils may be used. The heating surface is divided among the three coils as follows:

	Per Cent of Total Surface
2 side coils .....	84
1 swing pipe coil .....	16

Jackets are desirable if a tank must be kept warm a large proportion of the time. Hollow tile 4 inches thick, placed with the 8 inch by 12 inch surface to the weather, is recommended. A two inch air space between the tank and the jacket is advisable. This air space must be closed at the top and bottom.

## CHAPTER XVII

### VOLUME MEASUREMENTS

Gauge tables for oil storage tanks—Collection of field data—Calculations—Limits of error—Preparation of table—Horizontal tanks—Concrete tanks.

The collection of field data and the computation of the volume contained in a tank are interesting phases of the oil business. The volumes so computed are assembled into tables from which the number of gallons or barrels contained in the tank for any depth as shown by measurement, may be taken directly.

The field work consists in carefully measuring each tank. No two tanks built to the same plans will give identical measurements. One table for several tanks is convenient and, under certain conditions, allowable. Where tank measurements are involved in the purchase or sale of crude oil or its products, however, separate tables for each tank are advisable if the tank volumes at full capacity vary more than  $\frac{1}{100}$  of 1 per cent. If the variation is less than this amount, the volumes calculated for the various rings may be averaged and one table may be prepared. The tolerance figure given above represents an allowance corresponding to the volume contained in about one-eighth of an inch of tank depth. One-eighth of an inch is the smallest fraction which can be read on a gauge rod or tape with consistency.

Tables for refinery operation and stock tanks may be averaged and combined for a greater maximum variation. For this purpose, the convenience of working with the same tables overcomes the disadvantage of slight inaccuracies. In this case, a variation of one-tenth of 1 per cent. would be acceptable. Although the standards of different companies vary on this point, the above may be taken as a fair average.

In ascertaining the dimensions of vertical storage tanks,

measurements are taken around the circumference. This practice is termed "strapping the tank." The following discussion is based upon the assumption that the tape thus placed around the shell forms a perfect circle. This is not strictly correct but is sufficiently accurate for the purpose.

A two hundred foot steel band tape marked in feet and hundredths is the most satisfactory measuring instrument. A spring balance for maintaining a uniform tension on the tape is advisable. Adjusting the tape to avoid the rivet heads in the vertical seams, measurements are taken at the center of the rings. Although some companies measure each ring, the method in common use at the present time saves considerable time and labor, as follows:

Measure the 1st, 2nd, 3rd and top rings. If the tank is more than four rings high, interpolate for the dimensions of rings between the 3rd and the top.

This method eliminates the use of long ladders and gives results which are accurate within the limits of gauging. The top ring can be measured by having the tapemen lie face down on the roof.

The first step consists in marking the centerline of the ring to be measured with light chalk or Kiel marks at each seam and at the center of each sheet. These marks serve as a guide in preventing the tape from sagging. The tape is then placed around the tank from some selected and marked vertical seam to a seam at or near the end of the tape. Holding the tape at tension, this distance is carefully noted. The tape is then moved forward. In the case of tanks under 200 feet in circumference, one application is, of course, sufficient. Starting from a second seam of the ring, a second set of readings are taken. They should check within one ten thousandth or should be repeated. The readings are then averaged and entered as the circumference of the first ring. This method is repeated for the succeeding rings. At each ring, while the tape is stretched, the horizontal segment should be measured. This segment, shown in Fig. 177, is later to be deducted in conformity with the assump-

tion that the stretched tape is a true circle. The additional information to be obtained for each ring includes the number of vertical seams and the lap of each. Furthermore, the thicknesses of the plates should be checked from the specifications.



FIG. 177

Diagram of segment formed by tape and shell when "strapping" tank.

Vertical measurements should next be taken. The height is measured at the four quarter points from back to back of angles and the results are averaged. Working from the inside, the distances from edge to edge of plate, as shown in Fig. 178, should be measured at two or more points and averaged for each ring. The dimensions of manholes should be taken and their position should be measured with reference to the bottom.

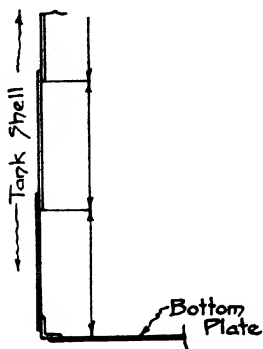


FIG. 178

Inside tank measurements.

The above measurements cover the complete shell. It is then necessary to "take the deadwood." This consists in measuring all structural material or other objects in the tank which displace oil. The only exception is the swing pipe. Since this pipe is usually full of oil and its location is variable it is usually omitted. No set rules can be formulated for taking this deadwood measurement.

The essential requirement is that the work should be so systematized as to avoid omissions. Measurements should be in feet and inches for reduction to cubic inches in the computations. One system is to start from the bottom and enter the notes somewhat as follows:

0' 0"-0' ½"	4" × C	leg of bottom angle.
0' 0"-0' 2"	7-24" × 24"	pads under columns.
0' 0"-0' 4"	30-4" × 12"	blocks under coils.
	8-4½" × 16"	blocks under coils.
0' 0"-0' 4"	½" × C	leg of bottom angle.
0' 0"-1' 4"	1-8" × 8"	block under swing.
0' 2"-0' 2½"	7-18" × 18"	Col. bearing plates.
0' 2½"-30' 3"	6-6" I beams.	Columns.
	1-8" I beam	Columns.
0' 4"-0' 6"	421 lin. ft. 2" pipe.	Heater coils.
	64-2" ells.	Heater coils.
1' 4"-1' 8"	24 channels.	[, set vertical, bracing.

This system gives the displacement data and shows where the obstruction occurs at the same time and in the exact order desired.

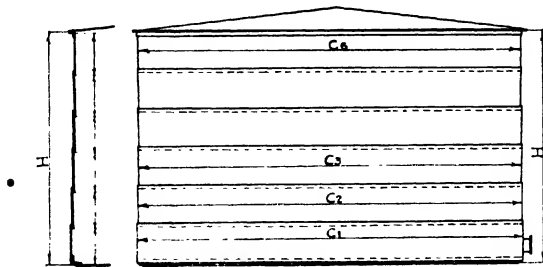


FIG. 179

Measurements taken when "strapping" oil tank for guage table preparation.

Figs. 179 and 180 show the measurements and field notes taken on a 54 by 30 foot tank.

Having obtained the above field data, the computations may be made. Since the field measurements give the circumference in feet, a formula which will reduce this quantity to gallons per inch is useful. A convenient equation requiring only one operation is

$$\text{gallons per inch} = \frac{\log^{-1} 1.3044604}{C^2}$$

$C$  = circumference in feet.

The above formula lends itself readily to computation with logarithms, seven place tables being advisable.

TANK	# 161	Weather - Fair	Date 9-6-22
Ring #1	t = 5/16"	Temp. 80°	Party
C <sub>1</sub> = 62772	from 0:0" to 4:11"		J. Smith (ch)
C <sub>2</sub> = 62764			R. Brown
2) 339536			E. Jones
62768			
12 laps @ 4 1/2"			
12 segments 5 1/4" x 14"			
Ring #2	t = 1/4"		
C <sub>1</sub> = 62765	from 4:11" to 9:9"		
C <sub>2</sub> = 62775			
2) 339540			
62770			
12 laps @ 4 1/2"			
12 segments 1/4" x 12 1/2"			
Etc.			

FIG. 180

Page from field book. Measurements of 54 foot x 30 foot tank.

The gallons per inch quantity as derived above is the volume enclosed by the tape. From this figure must be subtracted the displacement of the shell proper, segments and vertical laps. These can be reduced to gallons per inch as follows:

Let  $C$  equal the circumference, ft.

- $a$  " the length of segment, in. (Fig. 176.)
- $l$  " lap of plate, in.
- $n$  " number of vertical seams.
- $t$  " plate thickness, in.

$$\text{gallons per inch displaced} = \frac{t (24C + 2nl + na)}{462}$$

This displacement, subtracted from the gallons per inch, as compiled above, will give the net volume per inch for the various

rings, from which there remains to be subtracted only the dead wood in order to obtain the volumes as entered in the gauge tables.

For an orderly arrangement which can easily be checked, the author suggests the following, which is an example taken from Figs. 179 and 180 with deadwood taken from the notes above given.

## TANK NO. 161

Ring No. 1.  $C = 169.768$  from 0 ft. 0 in. to 4 ft. 11 in.

$\log C$  2.2298559

2

$\log C^2$  4.4597118

1.3044604

$\log$  gal. per in. 3.1552514

gal. per in. 1429.72 from 0' 0" to 4' 11"

Displacement—(shell, laps and segments)

$\frac{5}{16} [ (24 \times 169.768) + (2 \times 12 \times 4\frac{1}{2}) + (12 \times 14) ]$

gal. per in. =  $\frac{462}{2.942}$

gal. per in. = 2.942 from 0 ft. 0 in. to 4 ft. 11 in.

Net gal. per in. =  $1429.72 - 2.94 = 1426.78$  from 0' 0" to 4' 11"

## DEAD WOOD

0' 0" to 0' 0 $\frac{1}{2}$ "  $169.77' \times 12'' \times 4'' = 814.9$

$7 \times 24'' \times 24'' = 4032.0$

$30 \times 4'' \times 12'' = 1440.0$

$8 \times 4\frac{1}{2}'' \times 16'' = 576.0$

$169.77 \times 12'' \times \frac{1}{2}'' = 1018.6$

$1 \times 8'' \times 8'' = 64.0$

total cu. in. 7945.5

gallons displaced  $\frac{7945.5}{231} = 34.39$

Net volume from 0 ft. 0 in. to 0 ft. 0 $\frac{1}{2}$  in.

$1426.78 - 34.39 = 1392.39$  gal. per in.



$$\begin{array}{rcl}
 0' 0\frac{1}{2}" \text{ to } 0' 2" & 7 \times 24" \times 24" = & 4032.0 \\
 & 30 \times 4" \times 12" = & 1440.0 \\
 & 8 \times 4\frac{1}{2}" \times 11" = & 576.0 \\
 169.77 \times 12" \times \frac{1}{2}" = & 1018.6 \\
 1 \times 8" \times 8" = & 64.0 \\
 \hline
 \text{total cu. in.} & & 7130.6 \\
 \text{gallons displaced} & \frac{7130.6}{231} = & 30.87
 \end{array}$$

Net volume from 0 ft. 0½ in. to 0 ft. 2 in.  
 1426.78 — 30.87 = 1395.91 gal. per in.

$$\begin{array}{rcl}
 0' 2" \text{ to } 0' 2\frac{1}{2}" & 30 \times 4" \times 12" \\
 & 8 \times 4\frac{1}{2}" \times 16" \\
 169.77 \times 12" \times \frac{1}{2}" & \\
 1 \times 8" \times 8" & \\
 7 \times 18" \times 18" & \\
 \text{Etc.} & &
 \end{array}$$

This procedure is followed for each ring and for each section of each ring where there is any variation in the "deadwood." From the figures obtained as above and properly listed the gauge table may be conveniently prepared with the aid of an adding machine, especially if the machine is of the recording type with a repeat key. At each point where the volume changes, a check is obtained by multiplying the number of inches added by the gallons per inch value for the ring under consideration. Tables are usually prepared for each inch of height. For the interpretation of gauge readings involving fractional inches, a small insert giving the average gallons for each one-eighth inch should be inserted.

Some of the larger companies also take into consideration the expansion of the shell due to the head of oil in the tank. It is apparent that the stresses in the shell will sometimes elongate the circumference sufficiently to make an appreciable increase in the volume of the tank. The following formula may be used:

$$E = \frac{HC^2}{3,000,000 T}$$

- $E$  equals expansion of the circumference in feet.  
 $H$  " head of oil in feet.  
 $C$  " circumference of tank in feet.  
 $T$  " shell thickness in sixteenths of an inch.

In applying the formula, each ring should be figured for a head,  $H$ , from the center of the ring to the oil level when the tank is full. The correction,  $E$ , may then be added to the measured circumference,  $C$ , and the computations made as before. It is interesting to note that on a standard 55,000 barrel tank, this correction will add approximately 25 barrels or  $\frac{1}{20}$ th of 1 per cent. to the volume. Where oil is bought or sold in large tanks usually filled to capacity, the correction is warranted. For smaller tanks, refinery tanks, or large tanks in which selling gauges may vary from a few inches to full tanks, it is not to be recommended.

Horizontal tanks are more difficult to gauge. The average circumference should be measured and the corresponding average diameter computed. All dimensions being in inches, then in Fig. 181.

$$G = \frac{Lr^2}{462} (\text{rad } BAC - \sin BAC),$$

where  $\text{rad } BAC$  denotes the value of the angle measured in radians. The value of the angle  $BAC$  in degrees may be ob-

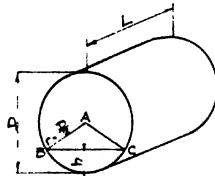


FIG. 181

Measurements taken on horizontal tanks.

tained from a table of versed series by noting that  $h/r = \text{vers } \frac{1}{2} BAC$ . Note:  $2\pi$  radians =  $360^\circ$ . The curve in Fig. 182 gives gallons per inch of length for all ratios of depth to diame-

ter up to 0.5, based on this formula, which is accurate for all horizontal cylindrical tanks with flat heads. When the depth of oil exceeds half the diameter of the tank, the curve may be used to determine the volume of the empty space above the oil, and the oil content is then obtained by deducting the volume of this space from the whole volume of the tank.

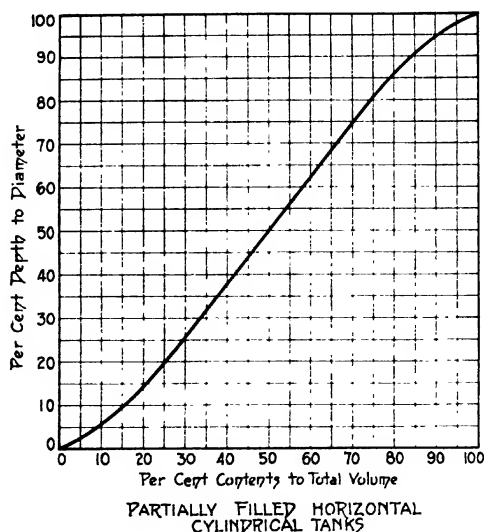


FIG. 182

Bumped heads usually add a further complication. The total volume of the head may be easily calculated by the use of solid geometry. In the field a string or tape may be stretched inside across a diameter from *A* to *B* and the rise *a* and diameter *d* measured. From the above, the capacity of the spherical segment in gallons *G* may be calculated as follows:

$$\begin{aligned}
 V \text{ in cu. in.} &= \frac{\pi a}{6} \left[ 3 \left( \frac{d}{2} \right)^2 + a^2 \right] \\
 G \text{ in gal.} &= \frac{\pi a}{6 \times 231} \left[ 3 \left( \frac{d}{2} \right)^2 + a^2 \right] \\
 &= \frac{a}{441} \left[ 3 \left( \frac{d}{2} \right)^2 + a^2 \right]
 \end{aligned}$$

For ordinary refinery tanks this quantity may be divided by the tank diameter and added to the shell volume for each inch. For tanks from which oil is bought and sold, however, except at half and full capacities, this method is not sufficiently accurate. In this case, the head may be assumed as a cone: or, in Fig. 183 the triangle  $ABC$  represents the volume  $\frac{1}{2} G$ . Let

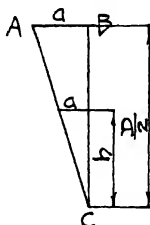


FIG. 183

Diagram, head volume relations.

$AB$  = the measured rise and  $BC = \frac{1}{2}$  the diameter  $d$  of the spherical segment. The volumes  $G_1$ ,  $G_2$ , etc. may then be proportioned directly as the ordinates  $A'$ , etc., or  $G'/G = a'/a = h'/(d/2)$ , where  $h$  is the depth of oil in inches. This method will give results within the gauging error limits and eliminates a large and tedious amount of calculation.

Gauge tables for small tanks are sometimes prepared by placing the tank on scales, filling it with water at known temperatures and recording the weight at predetermined depths of water in the tank. This procedure is only applicable to shop practice with special equipment.

In the case of concrete lined reservoirs, it is customary to place under the gauging hatch a steel plate about 3 feet square, securely anchored to the bottom. A perforated 10 inch pipe is often placed over the plate to act as a well and to guide the rod or tape. As the concrete is rarely exactly level, it is necessary to take very accurate readings over the bottom with the usual surveyor's level and rod. By carefully plotting contours at intervals of fractions of an inch, the volume contained up to the level of the gauge plate may be determined. From this point on,

the volumes per inch may be computed by solid geometry directly from the field measurements.

Oil tanks are measured, or to use the trade name, "gauged," by rods or tapes from the gauge openings in the roof or top. The oil level on the rod or the tape is noted and the temperature is taken by means of a thermometer suspended in the oil. The apparent contents of the tank at the recorded rod or tape reading is obtained from the table. Since the standard temperature for sales or transfers is 60° F., a plus or minus correction is made to bring the contents to the standard basis. If the oil in

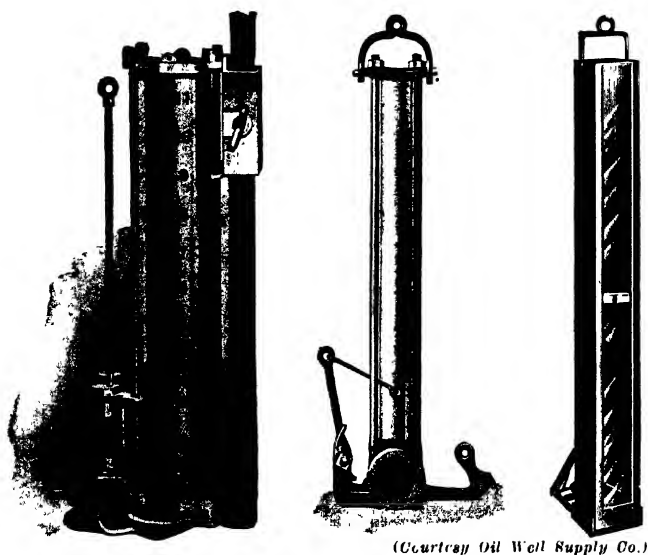


FIG. 184

Types of water-finders or "thieves."

the tank is under 60°, the correction is added, and if over 60° it is subtracted. The coefficient varies for different oils and its derivation is a complex subject. American refiners usually subtract or add 1 per cent. for temperature differences which vary with the different oils as follows:

	Temperature difference, °F.
Gasoline	15
Kerosene and heavy naphthas	20
Gas, fuel and lubricating oils	25

Tables are obtainable with this correction worked out. For a theoretical discussion of expansion and references to the literature thereon, the reader is referred to Bacon and Hamor, "The American Petroleum Industry," Vol. 1, p. 96.

Water from various sources is usually present and will settle to the bottom of the tank and the water content must be subtracted from the gross volume. The water is usually drawn off as much as possible. The depth of that remaining is then determined by "thieving." Fig. 184 shows types of the device used for this purpose. The apparatus is lowered to the bottom through the gauge hatch, closed, and then carefully withdrawn, bringing up a cylinder of fluid from which the water depth is read. This depth is referred to the table to reduce it to gallons or barrels, and subtracted from the total content. It should be noted that thieving is only necessary for inventories, or when an empty tank is filled, a tank pumped completely out, or when water is drawn off. For ordinary transfers the difference between a "before" and "after" gauge is entirely represented by oil volume, so that water may be neglected.

## CHAPTER XVIII

### BULK TRANSPORTATION

Pipe lines—Friction of oil in pipes—Pipe line construction—Station design—Pumping units—Pipe line costs—Tank cars—M. C. B. classification—Tank steamers—Tonnage—Voyage periods—Operating data—Harbor barges.

The great bulk of crude oil handled today is transported on land through pipe lines. This method far exceeds any other in economy. The usual pipe sizes are 4, 6, 8, 10 and 12 inch, with pumping stations from 12 to 60 miles apart, depending upon the topography of the region and the character of the oil pumped.

Steel line pipe is almost universally used. Line pipe differs from ordinary steel pipe only with respect to the length and thickness of the screwed couplings. The weights per foot including couplings and the test pressures of the usual sizes of steel line pipe are given below:

TABLE 56. LINE PIPE

Size, In.	Weight per Foot.	Test Pressure, Lbs.
		Lbs. per Sq. In.
4 .....	10.98	1,600
6 .....	19.367	1,500
8 .....	29.213	1,200
10 .....	41.644	1,000
12 .....	50.916	900

The usual pump pressure is 750 pounds per square inch. This limit is somewhat arbitrary but has been established as the highest pressure practicable with the present standards of valves, fittings, packing, etc. Except where topographic conditions are particularly difficult, the greater part of this pressure is consumed in line friction. With a reasonable working pressure and fairly easy topography, it is at once evident that the spacing of pump stations is dependent upon the line friction, which, in turn, depends entirely upon the character of the oil.

The determination of line friction is a complicated problem

and one upon which there is very little published data. It is obvious that the friction will vary with the viscosity of the oil and that the viscosity in turn will vary with the temperature.

The formula most used by the eastern transit companies is that of Forrest M. Towl. This formula, given below, was deduced from observation on Pennsylvania crude oil of 38° B. gravity. It may also be used successfully for Mid-continent crudes of about the same gravity.

$$p = \frac{9 B^2}{d^5} \quad (1)$$

$$B = \frac{d^{2.5}}{3} \sqrt{p} \quad (2)$$

$d$  = pipe diameter, inches.

$p$  = lbs. per sq. in. for line 10 miles long.

$B$  = barrels per hour.

In formula 1, 2 per cent should be subtracted from  $p$  for

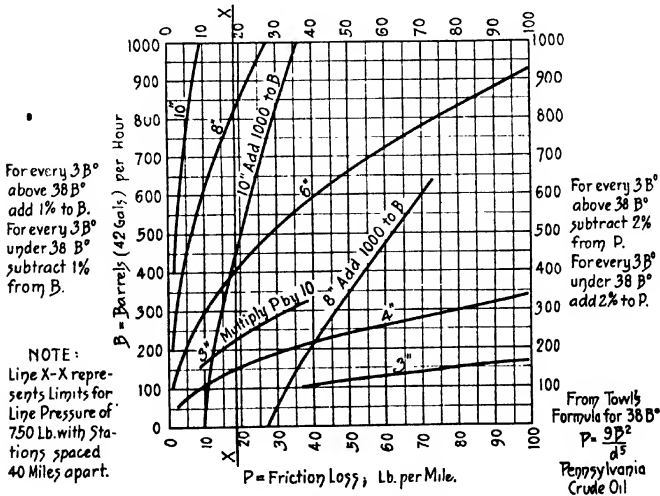


FIG. 185

Graphic presentation of Towl's formula for loss of head due to friction in oil pipe lines.

each 3° B. that the oil is above 38° B. and 2 per cent. should be added to  $p$  for each 3° B. that the oil is below 38° B. in gravity.



In formula 2, a correction factor of 1 per cent. should be similarly applied to a value of  $B$ . An allowance for temperature should also be made. For all practical purposes,  $1^\circ$  B added to or subtracted from the gravity for each  $10^\circ$  F. above or below  $60^\circ$  F. will be sufficient.

A chart based upon these formulae and giving an example of its use is shown in Fig. 185.

It should be noted that the temperature correction as above applied is volumetric only and does not relate to the viscosity. For this reason the Towl formula is not applicable to heavy viscous oils such as those from California. Experiments conducted by A. F. L. Bell with heavy California oil, of asphaltum base and of  $14\frac{1}{2}^\circ$  B. gravity at  $60^\circ$  F. show that the temperature in one of the vital quantities influencing the friction loss. A formula based on these experiments is as follows:

$p$  = Friction loss in lbs. per sq. in. per mile of pipe.

$d$  = Pipe diameter, inches.

$t$  = Temperature,  $^\circ$  F.

$B$  = Barrels per hour (42 gal.).

$$p = \frac{32768}{d^5} \left( \frac{9}{t - 40} \right)^2 \sqrt[3]{B}$$

The second factor assumes that the oil ceases to flow at  $40^\circ$  F., at which temperature  $B = 0$  or  $p = \infty$ .

Values of  $32768/d^5$  for different pipe sizes are given below:

Size of Pipe, In.	Value of $\frac{32768}{d^5}$
12 .....	.132
10 .....	.32768
8 .....	1.00
6 .....	4.214
4 .....	32.0

Charts based on the above for 6, 8, 10 and 12 in. pipe are shown in Figs. 186, 187, 188 and 189.

The difficulty introduced by varying weather conditions of correctly predicting the temperature of the oil in the line tends to reduce the accuracy of results obtained by the application of this formula. In using it, therefore, some leeway is advisable.

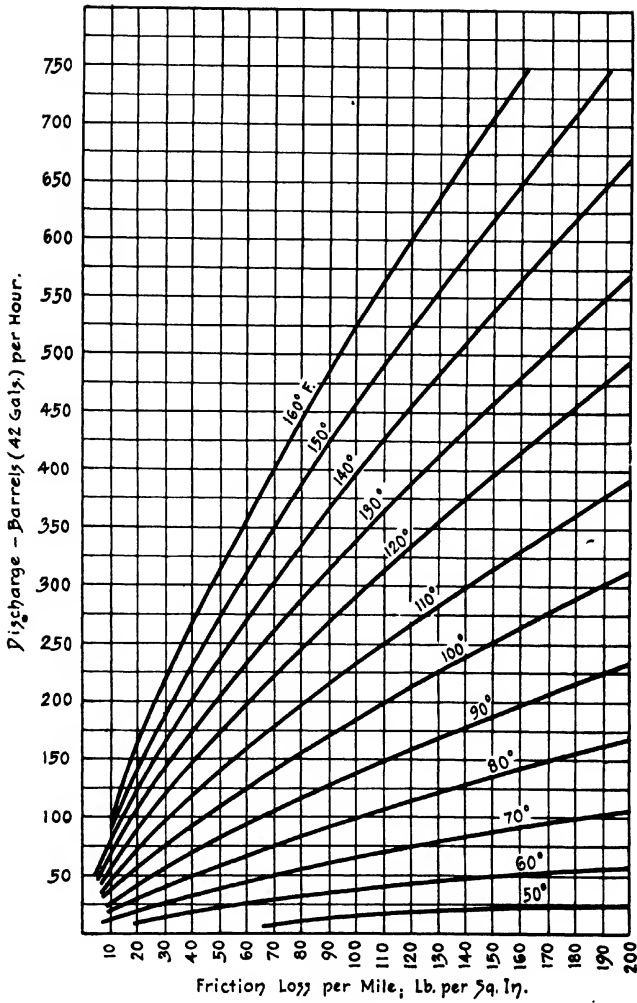


FIG. 186

Friction loss  $14\frac{1}{2}^{\circ}$  B. oil through 6 inch pipe line, A. F. L. Bell formula.

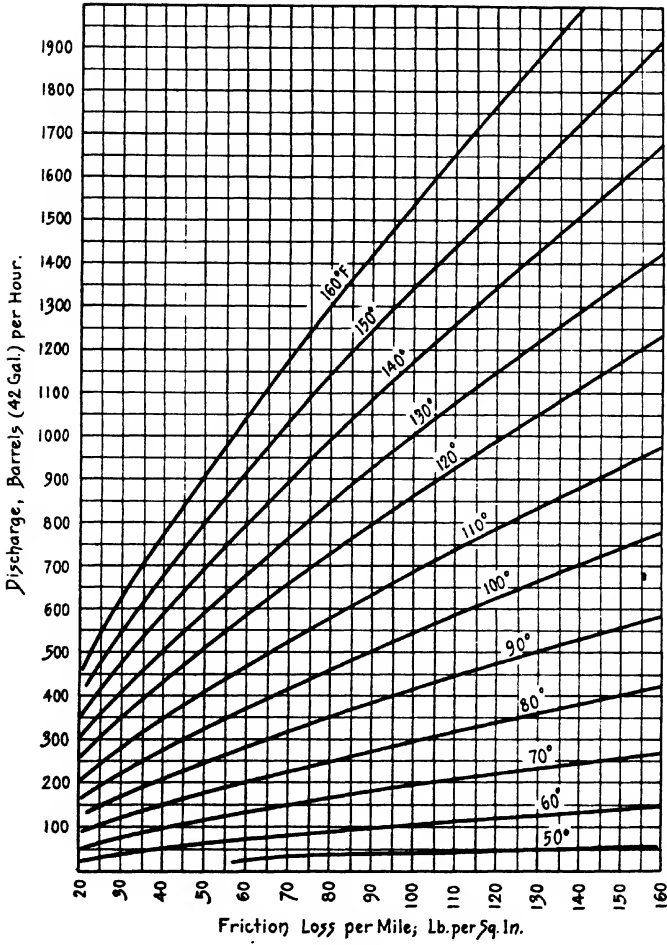


FIG. 187

Friction loss  $14\frac{1}{2}^{\circ}$  B. oil through 8 inch pipe line. A. F. L. Bell formula

For other oils than  $14\frac{1}{2}^{\circ}$  B. California petroleum, this formula is often used with the assumption that every  $10^{\circ}$  F. increase in temperature above  $60^{\circ}$  will raise the Baumé reading  $1^{\circ}$ . For instance, if  $12^{\circ}$  B. Panuco oil is raised to  $110^{\circ}$  F. its gravity will be  $17^{\circ}$  B., while the  $14\frac{1}{2}^{\circ}$  B. California oil will have a grav-

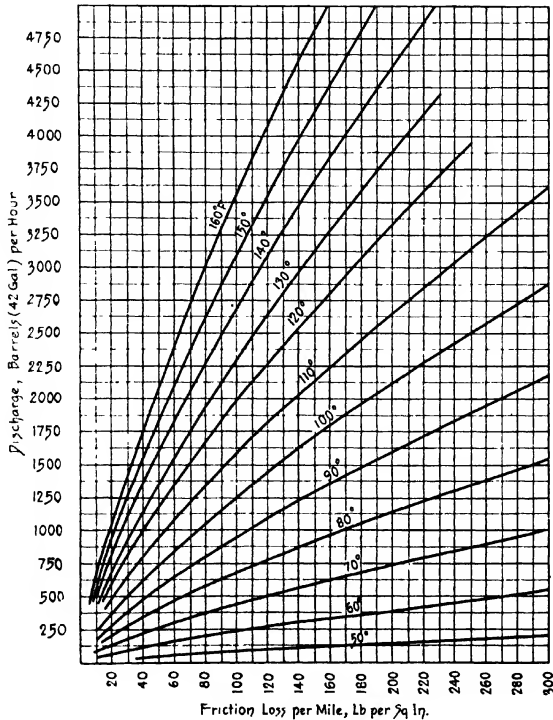


FIG. 188

Friction loss  $14\frac{1}{2}^{\circ}$  B. oil through ten inch pipe line. A. F. L. Bell formula.

ity of  $17^{\circ}$  B. at  $85^{\circ}$  F. The chart figures at  $85^{\circ}$  F. will therefore be used for problems involving Panuco oil at  $110^{\circ}$  F. In a similar manner, for  $16^{\circ}$  B. California oil, the gravity at  $100^{\circ}$  F. would be  $20^{\circ}$  B. since the  $14\frac{1}{2}^{\circ}$  B. oil would have this gravity at  $115^{\circ}$  F., the line friction for the  $16^{\circ}$  B. oil at  $100^{\circ}$  would be found under the chart temperature of  $115^{\circ}$  F.

The Towle and Bell formulae may be taken as the two extremes in solving problems in the transportation of oil through pipe lines. They are both empirical and for oils other than

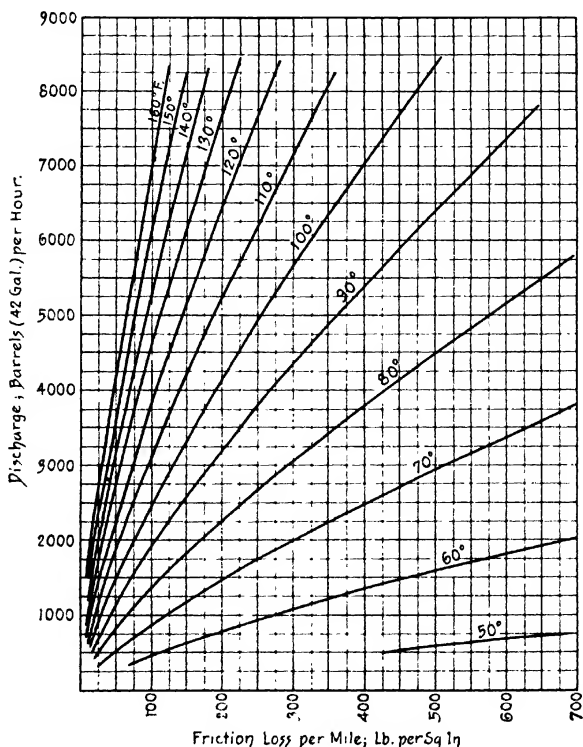


FIG. 189

Friction loss  $14\frac{1}{2}^\circ$  B. oil through twelve inch pipe line. A. F. L. Bell formula.

those upon which the development experiments were based must be used with caution. As a general theory leading to a method universally applicable, the following discussion should prove of interest.

With viscous liquids such as oil, two conditions of flow exist:

the first, viscous or "stream line"; and the second, turbulent. At low velocities, the liquid will flow in a filled pipe like an infinite number of cylindrical shells, each inner cylinder sliding past its adjacent outer neighbor. Under the first condition, the cylindrical layer next to the pipe walls moves slowly while the velocity of each succeeding cylinder increases until at the center the velocity is about double the average velocity for the entire diameter of the pipe. If the pressure on the line, and hence the velocity, were gradually increased, a point would be reached where the fluid would break down into eddies and whirls. Under this condition, which is known as a state of *unstable flow*, a further increase of pressure will not increase the velocity until a second point is reached, with still further pressure, where the velocity and discharge will again increase in proportion to further increments of pressure. This second state of flow where velocities are again relative to pressures, is called the *turbulent stage* of steady flow, the oil not flowing in stream lines but rather rolling through the pipe with a vortex motion. For lines carrying heated oil, velocities in this second stage will retard to some extent the loss of heat from the pipe and hence also retard the increase of viscosity in the portions adjacent to the walls of the pipe.

The velocity at which the change in character of flow takes place is known as the *critical velocity*. This critical velocity varies with different conditions, being a function of the viscosity and the gravity of the oil and of the pipe diameter.

Viscosity is the resistance to internal movement, one upon the other, of minute particles of the mass. It may be regarded as the internal friction. Absolute viscosity is the force in dynes necessary to move a surface of 1 square centimeter past an equal parallel surface 1 cm. distant with a velocity of 1 cm. per second, the space between being filled with the fluid whose absolute viscosity is sought. This viscosity is expressed in dynes per square cm., its unit being the *poise*, equal to 1 dyne per square cm. *Kinematic* viscosity is the absolute viscosity divided by the specific gravity.

Viscosities taken with the usual viscosimeters, as previously described, may be transposed to kinematic viscosities by the formulas used by the Bureau of Standards, as follows:

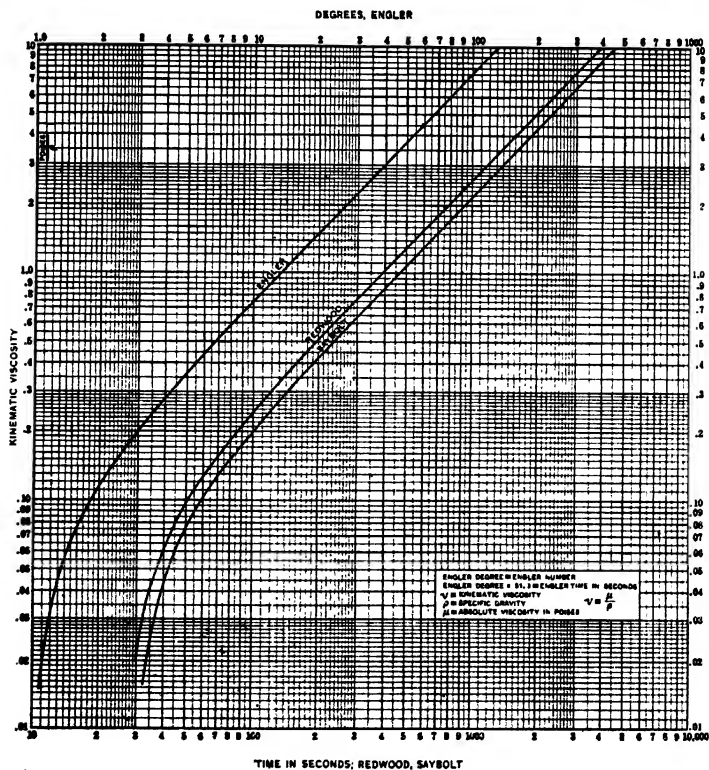


FIG. 190

Relation of Saybolt, Redwood and Engler viscosities to kinematic viscosities.

$$\begin{aligned} \text{Kinematic viscosity} &= .0022S - \frac{1.80}{S} \\ &= .00147E - \frac{3.74}{E} \\ &= .00260R - \frac{1.715}{R} \end{aligned}$$

$S$  = Saybolt time, seconds.

$E$  = Engler number.

$R$  = Redwood time, seconds.

The chart shown in Fig. 190 gives values for viscosities ordinarily encountered.

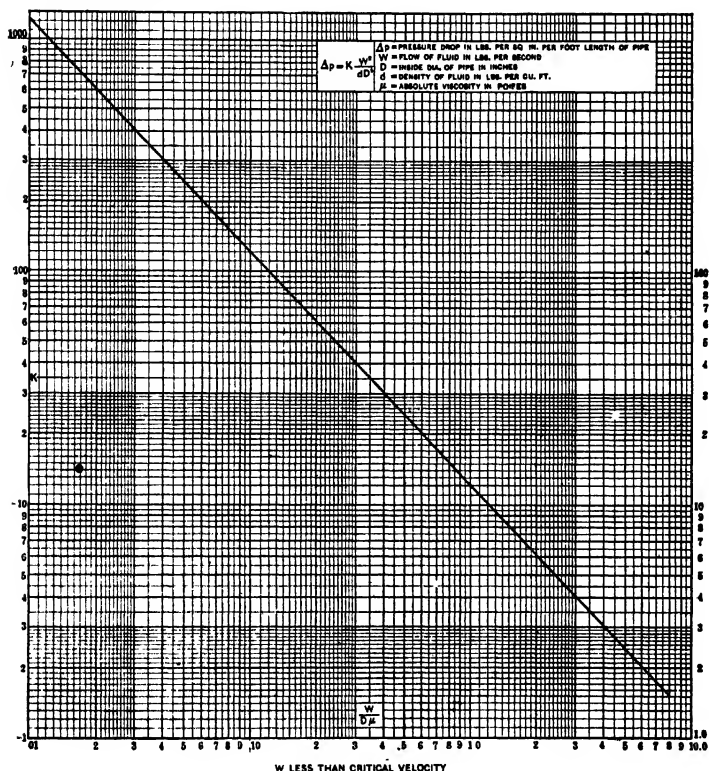


FIG. 191

Relation of coefficient  $K$  and  $W/d\mu$  when  $W$  exceeds the critical velocity. From experiments of Stanton and Pannell. (Courtesy Power Specialty Co.)

Stanton and Pannell,<sup>1</sup> from a series of experiments, offer the formula:

<sup>1</sup> (See Philosophical Transactions, Royal Society, Vol. 214, 1914.)



$$\Delta p = K \frac{W^2}{dD^5}$$

$\Delta p$  = Pressure loss in pounds per square inch per foot of length.

$W$  = Weight of fluid flowing, pounds per second.

$d$  = Density of fluid, pounds per cubic foot.

$D$  = Inside diameter of pipe, inches.

$K$  = A coefficient which is a function of  $W$ ,  $D$  and  $\mu$ ,  $\mu$  being the absolute viscosity in poises.

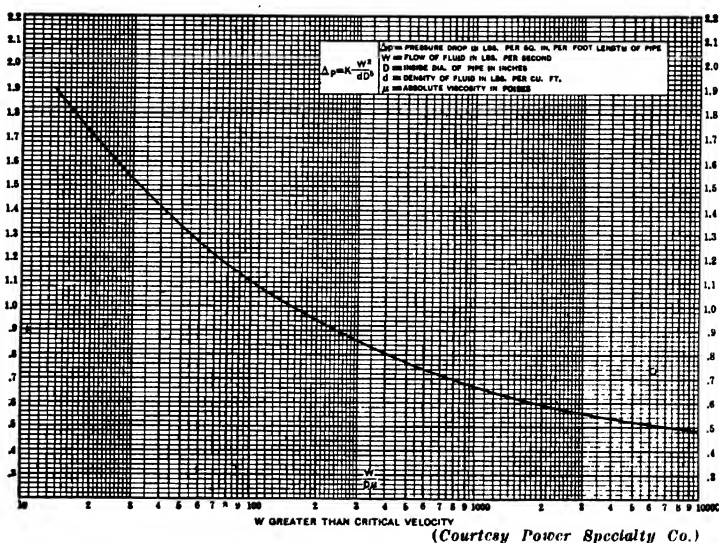


FIG. 192

Relation of coefficient  $K$  and  $W/d\mu$  when  $W$  is less than the critical velocity.  
Experiments of Stanton and Pannell.

The curves shown in Figs. 191 and 192 give values of  $K$  for velocities below and above the critical velocity. The critical velocity is really a *range* of velocities, from  $V_c = (25 v)/D$  to  $V_c = (40 v)/D$ , where

$v$  = kinematic viscosity,

$D$  = Inside pipe diameter, inches.

Intermediate values have been omitted from the chart.

The units given above are not consistent with the usual units of volume and gravity used in America.

The curves shown in Fig. 193 may be used to convert the usual barrels (42 gal.) per hour into pounds per second for

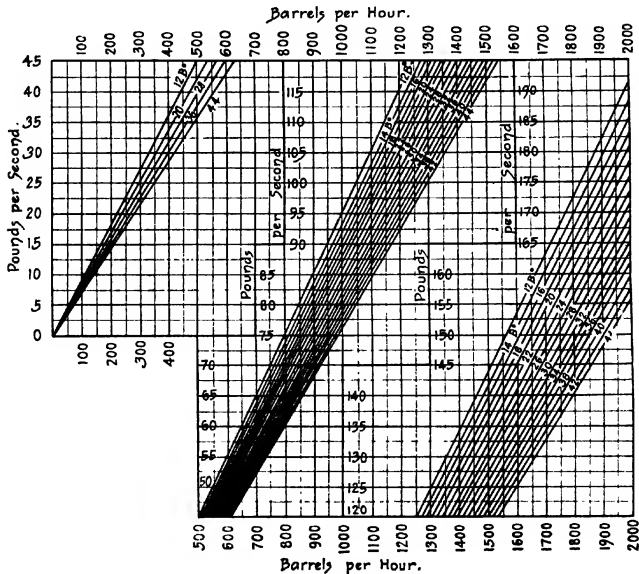


FIG. 193

Relation of barrels per hour, Baumé gravity and pounds per second.

various Baumé values. Fig. 194 gives values of  $d$ , the density, in pounds per cubic foot and Fig. 195 is a chart for determining the change in  $^{\circ}$  B. for temperatures other than  $60^{\circ}$  F. Fig. 195 is approximate but is sufficiently accurate for pipe line calculations. By means of these charts the usual units of American practice may be readily transposed for use in the Stanton and Pannell formula.

The change in the viscosity of an oil due to changes in temperature does not seem to follow any known law. Oils which have similar viscosities at one temperature may have widely varying viscosities at another temperature. For this reason, in

order to apply the above formulae, it is necessary to have the viscosity of the oil taken at several temperatures near the temperature which is expected to prevail in the pipe line under

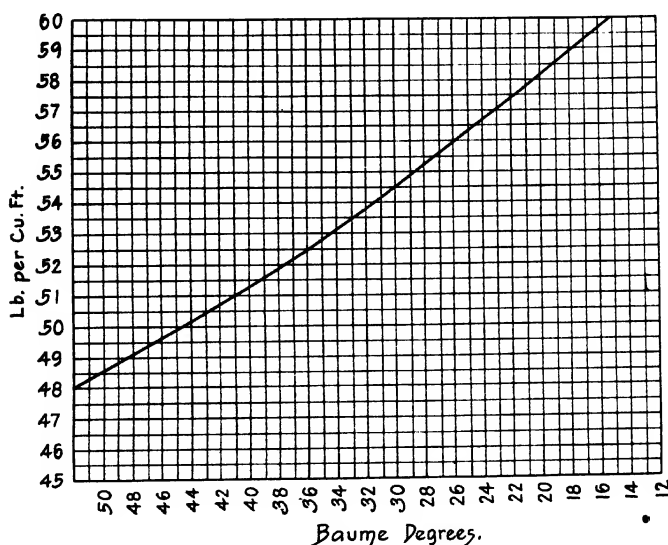


FIG. 194

Relation of Baumé degrees to pounds per cubic foot.

investigation. The viscosity may often be known at one temperature only, it being impossible to obtain more readings. The viscosity at the working temperature is then a question of judgment guided by the charts.

As an example, let the following assumptions be made:

Gravity of oil (at 60° F.) 18° B.

Average line temperature 125°.

Viscosity at 125°, 12 Engler = 450 Saybolt.

Length of line, 10 miles.

Barrels per hour, 500.

Diameter of line, 8 inches.

Required the friction loss.

The gravity of the oil at 125° F. is 21.9° B. = 0.9217 specific gravity and the density is 57.9 lbs. per cubic foot. The weight flowing per second is 43.5 pounds. From Fig. 189 the kinematic

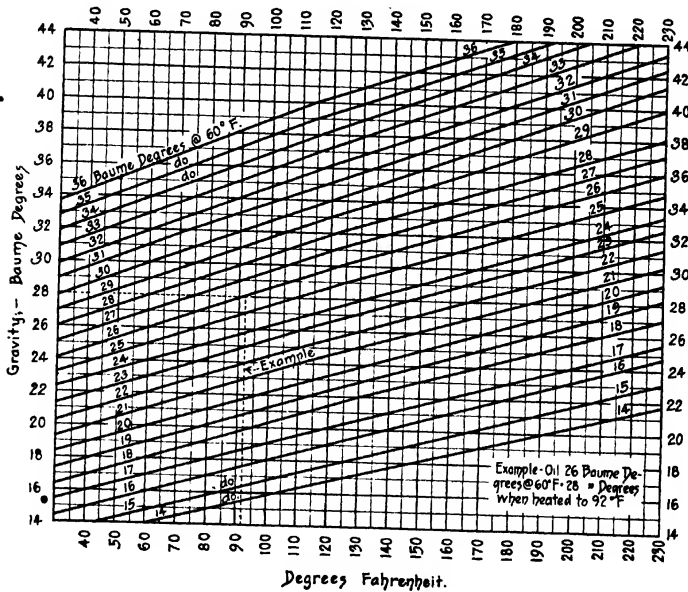


FIG. 195

Change of gravity (Baumé) due to temperature.

viscosity is 0.90. Since kinematic viscosity = absolute viscosity divided by the specific gravity,

$$\text{Absolute viscosity} = 0.90 \times 0.9217 = 0.83 \text{ poises.}$$

The ordinates of Figs. 191 and 192 are in terms of  $W/D\mu$ , where

$W$  = weight of oil flowing per second, pounds = 43.5.

$D$  = Diameter of line, inches = 8.

$\mu$  = Absolute viscosity, poises = 0.83.

Hence the value of the ordinate found on Fig. 190 is

$$\frac{43.5}{8 \times 0.83} = 6.56$$

Showing that  $W$  is less than the critical velocity and that the flow is stream line in character.

The coefficient  $K$ , as found from the chart = 1.85. Since we now have all the values for substitution in the general formula

$$\Delta p = K \frac{W^3}{dD^5} = 1.85 \times \frac{43.5^3}{57.9 (8^5)} = 0.00184 \text{ lbs. per sq. in.}$$

$$\text{Loss per mile} = 9.7 \text{ lbs. per sq. in.}$$

$$\text{Loss for 10 miles} = 97 \text{ lbs. per sq. in.}$$

For a second example, let the following assumptions be made:

14½° B. Kern River oil at 60° F.

Line temperature, 120° F.

1,000 bbl. hour = 155 lbs. per sec.

8 inch pipe.

In this case,

Viscosity at 120° = 15 Engler.

Gravity at 120° = 17.4° B. = .9498 sp. gr.

Density = 59.2 lbs. per cu. ft.

Kin. viscosity = 1.1.

Abs. viscosity = 1.1 × 0.9498 = 1.04.

$$\frac{W}{D\mu} = \frac{155}{8 \times 1.04} = 18.64.$$

$K = 1.75.$

$$\Delta p = 1.75 \times \frac{155^3}{57.9 (8^5)} = 1.75 \times \frac{24,025}{57.9 \times 32,768}.$$

Loss per foot = .0222 lbs. per sq. in.

Loss per 100 ft. = 2.22                      "

Loss per mile = 117                              "

Friction loss due to the resistance of pipe fittings must be

taken into consideration. The most convenient way to express this resistance is in equivalent lengths of straight pipe expressed in diameters of the line. The following table prepared from experiments will act as a guide:

TABLE 57. RESISTANCE OF VALVES AND FITTINGS

Fitting	Stream Line Flow		Turbulent Flow
	Under 80°	Over 80°	
Gate valve $\frac{3}{4}$ open . . . . .	4	8	11
" " " " . . . . .	20	40	100
" " " " . . . . .	50	100	900
Angle valve, open . . . . .	20	40	110
Globe valve, open . . . . .	25	50	135
Elbow, 3 diam. radius . . . . .	1.5	3	5
Flange . . . . .	4	8	35

Temperature has decidedly more effect on resistance at the low velocities prevailing in stream line flow than in the higher turbulent velocities.

In order to use the table, the equivalent diameters for the resistance represented by the fittings on the line should be reduced to lineal feet of line and added to the total length. Using the new length the calculations are made as before.

If the line crosses uncultivated country and carries light or non-viscous oil, the pipe is laid directly on the ground. This method allows constant inspection and facilitates repairs. Where the land is cultivated or the oil is of a viscous nature and must be kept hot, the line is buried under about 18 inches of soil. The work is divided between ditching gangs and laying gangs. In easy country, where transportation is not difficult, a mile of line can be laid in a day. Prior to covering, it is important to give the pipe a thorough coat of protective paint. Where the working temperature of the line is not excessive, asphalt paints are economical and effective.

The spacing of stations is determined by the practicable maximum working pressure of 750 pounds per square inch. This pressure must overcome the static head and the line friction. In the United States, the maximum and minimum spacing of stations are about 12 and 60 miles apart respectively. For light

oils with normal static heads, the usual station interval is about 40 miles. For the very heavy, viscous oils, station spacing is around 15 miles.



FIG. 196

Trench-digging machine on pipe line work.

At each station, it is customary to have at least two storage tanks. While one is filling, the station pumps can pull from the other. This arrangement simplifies the gauging of the oil quantities and makes it possible to keep shipments of different grades of oil separate. With the older lines the customary tank size is 30,000 barrels each, while more modern installations use 55,000 barrel tanks. In any case, the capacity of each of the two tanks should equal or exceed the daily capacity of the pumps. Stations strategically located for the accumulation of crude often have immense tank capacity. Some oil tank "farms" connected with stations have upward of 400 steel storage tanks.



(Courtesy Worthington Pump & Machinery Corp.)

FIG. 197

Interior of pumping station showing Diesel engines driving horizontal oil line pumps. Total horse power 1,650. Combined capacity of pumps 110,000 barrels daily.



The pumping equipment of the older stations usually consists of a battery of boilers with multiple expansion steam pumping engines. A separate boiler house and pump house are invariably installed to reduce the fire risk. Where heavy, viscous oils which must be heated are handled, this type of station is advisable since the boiler would be necessary in any case to keep the oil hot and the exhaust steam can be used for this purpose. For non-viscous crudes, such as those of the Mid-Continent field, Diesel type crude oil engines geared to power line pumps have been adopted by many of the pipe line companies in equipping their more modern stations. These engines will operate on the crude passing through the line with very favorable economy. The use of boilers is entirely eliminated. Fuel consumption guarantees can be obtained of 0.48 lbs. per brake horse power hour at full load, 0.50 lbs. at  $\frac{3}{4}$  load and 0.57 lbs. at  $\frac{1}{2}$  load on 18,500 B.t.u. oil. Figs. 197 and 198 show the interior and exterior of a modern station of this type.

There is one vital point to consider in the arrangement of an oil pumping station equipped with Diesel engines. Where the pumps and engines have been installed in the same room, accidents have sometimes occurred due to leaking gaskets or fittings. In such cases the room has been filled with an inflammable mixture of oil vapor and air which has become ignited from poor insulation of the engine exhaust or from other causes. For this reason, a firewall between pumps and engines, with close fitting openings for the shafts, is recommended. Properly placed exits for employees are advisable. An outside manual engine trip should also be provided.

The advantage of the installation of Diesel oil engines as compared with steam driven pumps is still an open question. The original transit lines using steam pumps were designed with small boilers carrying only 90 or 100 pounds per square inch steam pressure. This practice was uneconomical, and companies turned to the Diesel engine with power pumps. Engineering advances made in recent years have developed large unit boilers with high pressures and superheat. As a result, modern steam

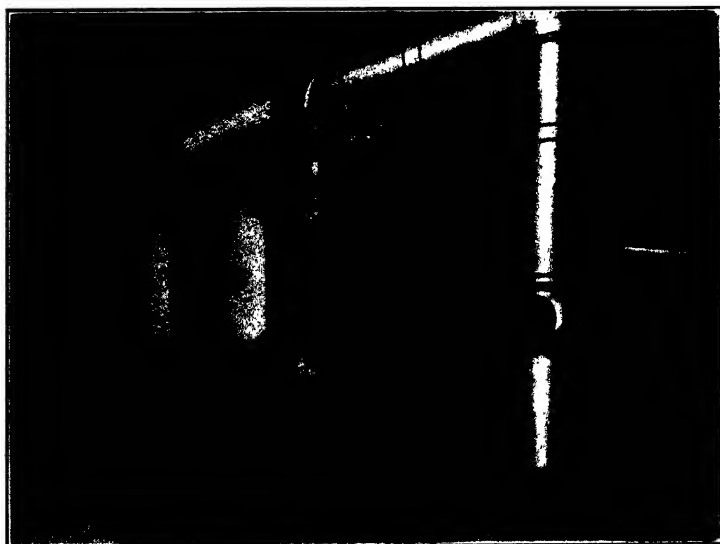


FIG. 198

Exterior of pump station on Sinclair pipe line using Diesel type oil engines.



pumping units are approaching the Diesel engine plants in commercial efficiency. One of the largest companies is now installing three pumping engines of the cross compound type. These engines will operate with a steam pressure of 200 pounds per square inch and 100 degrees of superheat. Each unit will handle 2,000 barrels per hour. The engines are of 500 indicated horsepower each. The expected steam consumption is 10 pounds per horsepower hour. Burning oil at 13 pounds of evaporation per pound of oil, the fuel consumption will be 0.77 pounds per horsepower hour. A Diesel plant will develop equal output on 0.57 pounds of oil per horsepower hour with a mechanical efficiency of 85 per cent. for the pump and engine set.



*(Courtesy National Transit Pump & Machine Co.)*

FIG. 199

Triple flywheel steam pumping engine. Wood station, Prairie Pipe Line Co.

The advantages of large steam units are claimed to be lower installation cost, lower depreciation, reliability and low fire risk. These advantages are contended to offset the lower fuel con-

sumption and operating labor costs of the Diesel type station. Where the exhaust steam may be utilized, the decision would seem to lie in favor of a modern steam plant. For other conditions, the installation should be given careful study before a decision between the two types is made.

While pipe line transportation is economical, it requires large capital investments. Recent estimates on 90 miles of 6 in. and 8 in. lines are reproduced herewith. The topography was flat with only one river crossing of any size.

TABLE 58. ESTIMATES OF PIPE LINE COSTS

	6-In. \$ per Mile	Per Cent of Total	8-In. \$ per Mile	Per Cent of Total
Surveys and legal expense . . . . .	111	1.5	111	1.1
Right of way . . . . .	150	2.0	150	1.5
Line pipes . . . . .	4,595	61.3	6,240	61.9
Freight . . . . .	870	11.5	1,305	13.0
Unloading and stringing . . . . .	267	3.6	400	4.0
Laying pipe . . . . .	427	5.7	640	6.4
Painting pipe . . . . .	50	0.7	65	0.7
Ditching and covering . . . . .	612	8.1	725	7.2
Camp expense . . . . .	200	2.7	200	2.0
Tools . . . . .	50	0.7	65	0.6
Telephone system . . . . .	165	2.2	165	1.6
Total per mile . . . . .	\$7,497	100.0	\$10,066	100.0

Estimated costs in 1921 on Diesel engine stations with two 55,000 barrel tanks each, complete with all auxiliaries such as electric lighting equipment, air compressor, water well, etc., are \$149,500 and \$186,750 each for capacities of from 9,000 to 10,000 and from 19,000 to 20,000 barrels per day respectively.

Pipe line operating costs are dependent upon many conditions. A statement of one of the principal companies shows the ratio of these costs in per cent. of the total, as follows:

Maintenance . . . . .	13.9
Transportation . . . . .	28.6
General expense . . . . .	11.0
Depreciation . . . . .	46.5
Total . . . . .	100.0

The cost per 1,000 barrel miles, the usual unit of comparison, will vary almost directly with the per cent. of capacity at which

the line is operated. Depreciation and general expense are nearly constant. Maintenance will vary slightly while the only change in transportation cost is for fuel. For this reason, it is imperative to keep the line running as near to full capacity as possible.

In 1913, typical operating costs per 1,000 barrel miles, for lines equipped with Diesel engine power were

No.	Cents
1 .....	34.28
2 .....	36.29
3 .....	39.63
Average .....	36.73

A study of these costs in detail would indicate an increase of about 75 per cent. in 1921.

Low costs and fairly large profits have led to governmental investigations and all interstate lines are now adjudged common carriers and come under the Interstate Commerce Commission. It may prove harmful to control rates too closely. It must be



(Courtesy American Car and Foundry Co.)

FIG. 200

Modern tank car.

realized that unlike the railroads, a pipe line company's business may quickly disappear if a pool becomes exhausted. Fairly high

depreciation rates should be allowed, therefore, in order that the cost of the line may be written off in a reasonably short time. Pipe lines perform a valuable economic function, and on account of their semi-speculative nature should be allowed a gross profit which will warrant a high amortization rate.

For the bulk transportation of crude oil and its products by rail, the tank car has been developed, as shown in Figs. 200 and 201. The modern tank car embraces a horizontal steel tank on a wood or steel underframe mounted on regular car trucks. The Master Car Builders Association has classified tank cars under the following headings.

- Class I. Tank cars for general service with wooden or steel underframes or without underframes, built prior to 1903.
- Class II. Tank cars for general service with steel underframes or without underframes, built between 1903 and May 1, 1917.
- Class III. Tank cars for general service built after May 1, 1917.
- Class IV. Tank cars for the transportation of volatile inflammable products whose vapor pressure at 100° F. exceeds 10 lbs. per square inch, built after May 1, 1917.
- Class V. Insulated tank cars of specially heavy construction built after January 1, 1918, for the transportation of liquid products whose properties are such as to involve danger or loss of life in the event of any leakage or rupture of the tank.

A new car built for ordinary service will come under Class III and a brief outline of the M.C.B. specifications for such a tank car may be of interest.

The calculated bursting pressure of the tank must not be less than 300 lbs. per square inch.

The minimum plate thickness shall be as follows:

Diam. of Tank	Bottom Sheet	Shell Sheet	Dome Sheet	Tank Heads	Dome Head
(Dimensions in Inches)					
60 or under.....	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{8}$
60 to 78.....	$\frac{1}{8}$	$\frac{5}{16}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{8}$
79 to 96.....	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{8}$

For tanks without underframes, the minimum thickness of bottom sheet shall be  $\frac{5}{8}$  inch. All seams shall be double riveted with the exception of the dome head seam which may be single riveted. The efficiency of seams shall not be less than 70 per cent. of the strength of the thinnest plate. Seams shall be caulked both inside and outside.

Modern cars are usually built with tanks of 6,000, 8,000 and 10,000 gallon capacities. The approximate tank dimensions are as follows:

Capacity, Gal.	Diameter, In.	Length Exclusive of Heads
10,000	87 $\frac{1}{2}$	31 ft. 9 in.
8,000	78	31 ft. 10 in.
6,000	72 $\frac{1}{2}$	27 ft. 8 in.

The length for 8,000 and 10,000 gallon tank cars is approximately 39 feet and for 6,000 gallon cars 35 feet from center to center of couplings. Domes are installed to allow for expansion, gauging, etc. Dome capacity of not less than 2 per cent. should be allowed.

Special types of cars are those insulated for casing head gasoline service, compartment (2 or 3) cars for less-than-carload bulk shipments and cars equipped with steam heater pipes for heavy viscous products.

One of the first vessels constructed for the carriage of petroleum in bulk was the iron sailing ship *Atlantic* which was built on the Tyne in England in 1863, sheet iron bulkheads being fitted to divide the hold into compartments.<sup>1</sup>

The first steamer built for carrying oil in bulk was launched

<sup>1</sup>For much of the information upon tank ships conveyed herein the author is indebted to Captain J. G. Johnson, American Society of Marine Architects.

in 1872, at Jarrow-on-Tyne, by the Palmer Shipbuilding Company, for the Red Star Line, a company organized largely by American interests for operation under the Belgian flag between

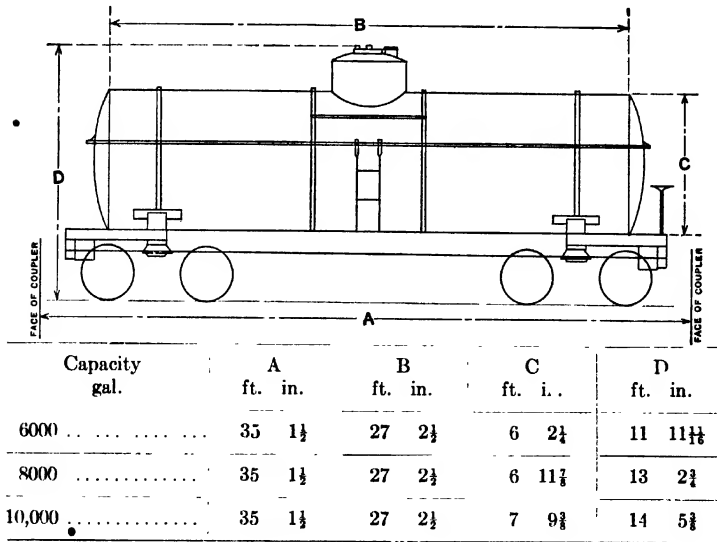


FIG. 201

Clearance dimensions of American Car and Foundry Co.'s tank cars.

Antwerp and Philadelphia. This vessel was named the *Vaterland* and was provided with passenger accommodation; but there is no record that she or her sister ships, the *Nederland* and *Switzerland*, built in 1873 and 1874, ever carried a cargo of oil.

The pioneer steamer to load a bulk cargo of oil in America was the Norwegian steamer *Stat* which sailed from Philadelphia for Ruen in 1879.

It is claimed that the present-day design of bulk oil carriers was evolved from a vessel designed and constructed at Armstrong's, on the Tyne, in 1886. This vessel had a length of 300 feet, a beam of 37 feet and a depth of 24 feet, with a sea speed of eleven knots per hour. The hull was divided into compartments by transverse bulkheads and subdivided longitudinally



by a centerline bulkhead. Between the main and the upper decks, an expansion trunk was arranged, fitted with transverse and longitudinal bulkheads. The machinery and boilers were placed aft and the pump room, which extended across the vessel, formed a cofferdam between the stokehold and oil compartments.

The first bulk oil carrying steamer constructed in this country was built in 1890, having a capacity of 500,000 gallons of oil. Great advances in tank ship construction have been made in recent years and there are bulk oil carriers afloat today with a capacity of over 15,000 tons or more than 4,000,000 gallons.

The coastwise tanker of average size has a capacity of about 7,000 tons or approximately 2,000,000 gallons of oil. These ships are usually 375 feet long by 52 feet in beam, with a draft of 24 feet, 6 inches.

The average transatlantic tanker carries about 10,000 tons, or 3,000,000 gallons. This size of ship is said to give maximum operating economy, the usual dimensions being 420 feet long by 55 feet in beam and 26 feet draft.

The large 15,000 ton tankers are used almost exclusively for long hauls of crude oil from foreign fields to refining centers. They are operated only between definite points of shipment and discharge. These vessels would not be practicable in general service owing to their large draft, which necessitates deep water harbors for discharging cargoes. Most of these large tankers are engaged in the Mexican crude oil trade. They are about 527 feet long, 66 feet, 6 inches in beam, and 34 feet in depth, the loaded draft being 28 feet.

One of the important considerations in the successful operation of oil tank ships is to move them with a full cargo. Unfortunately, owing to their excessive draft when fully loaded, many of the oil tank ships now in operation, even though of comparatively recent design, cannot be taken into all important ports except with a partial load. The new ships of the Sinclair Navigation Company, with a deadweight tonnage of 10,600 tons, have a draft when fully loaded of only 25 feet, 6 inches, as compared with a draft of 26 feet, 6 inches for the ordinary tank ship of the same tonnage.

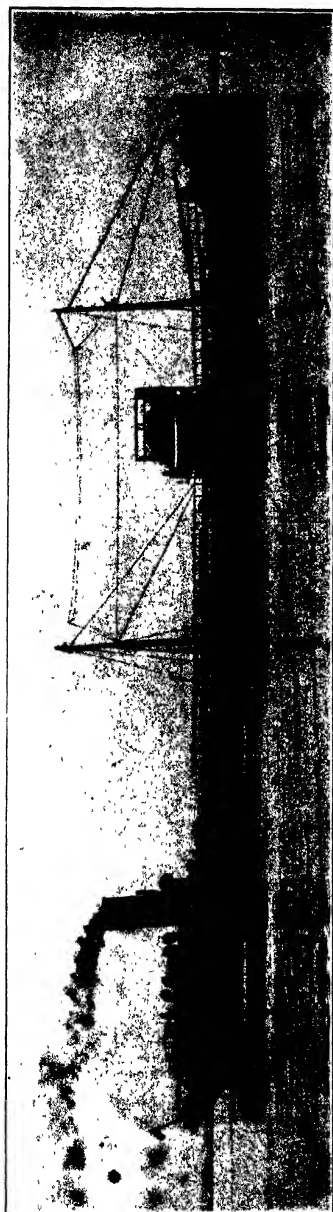


FIG. 202

Tank steamship "Albert E. Watts" of the Sinclair Navigation Co.

Since in many instances, this one foot difference in draft means taking the ship into port with a full load, where the ordinary vessel would be compelled to travel with a partial load, it represents a large increase in the value of the ship. This advantage is gained quite easily by increasing the beam one foot and by increasing the length ten feet. Moreover, this change is made without sacrifice of speed.

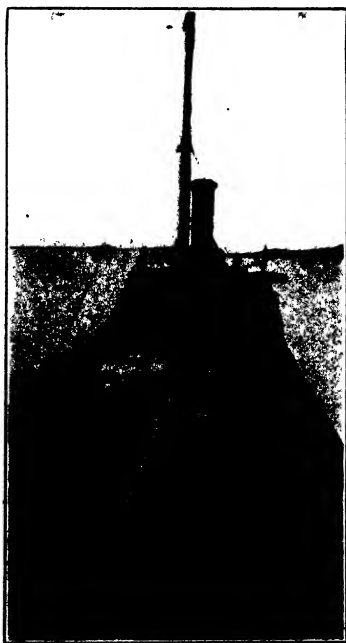


FIG. 203

Deck view S.S. Albert E. Watts.

These points indicate in a general way, the advantages which are now possible in oil tank ship construction. For those specially interested in the subject, however, more detailed information may be desirable.

These ships have an overall length of 445 feet, a breadth of

59 feet, 3 inches, and a depth of 33 feet, 3 inches. As previously noted, the draft is 25 feet, 6 inches. They have a sea speed of eleven nautical miles per hour. These vessels are single screw steel steamships, built with the Isherwood longitudinal system of framing, having raised poop, bridge and forecastle decks, and are rigged as a two-masted fore and aft schooner. The machinery is located aft. The pump room is amidships. They are provided with a duplicate electric light plants and with auxiliary machinery of the most modern type.

Until about 1910, the motive power generally adopted for tank steamers was the triple expansion surface condensing engine in combination with Scotch boilers. In that year, the first full-powered ocean going tanker *Vulcanus* was equipped with Diesel engines. This vessel has a cargo capacity of 1,100 tons. She is fitted with one Werkspoor reversible 500 brake horsepower Diesel engine, running at 180 revolutions per minute and giving the ship a speed of  $8\frac{1}{2}$  knots with a fuel consumption of 13 barrels of oil in 24 hours.

Within recent years, many tankers have been equipped with internal combustion engines of various design. While oil tankers are specially adapted for this class of motive power owners have remained skeptical as to the advantages claimed for the motor engine over the reciprocating steam engine. As a result, oil engines have not been generally adopted. Great advances in the design of internal combustion engines have been made, however, and, as results obtained from oil engine driven vessels actually in service become more fully known, it is probable that the motor tank ship will become more generally adopted.

The majority of the large tankers are equipped with quadruple reciprocating steam engines and Scotch boilers with superheaters. Geared turbines have been fitted to a number of tankers in the past two years and are reported to be satisfactory. All the modern tankers are equipped for the burning of liquid fuel. The chief advantages are the rapidity and ease of fueling, the reduction in bunker space, the increase in available cargo space accomplished by utilizing the double bottoms and other places on

shipboard where coal could not be conveniently stored, the reduction in the crew, and cleanliness in handling. The fuel space may be roughly taken as 45 cubic feet per ton for coal and 38 cubic feet for oil. Moreover, the heat value per pound of oil exceeds that of a pound of coal.



FIG. 204

Boiler, S.S. Albert E. Watts.

The pumping arrangements in large crude oil tankers usually consist of specially designed pumps ranging in size from 16 inches by 10 inches by 18 inches to 20 inches by 16½ inches by 24 inches, with 12 inch suctions and 10 inch discharge lines. Several points of discharge are provided on either side of the vessel. The pumps will handle from 1,200 to 2,200 barrels per hour each.

For a vessel intended to carry several grades of oil at one time, it is necessary to give particular attention to the pump-

ing arrangement so that two or more grades can be discharged at the same time. In a 10,000 ton deadweight ship of this class, it is usual to have two pump rooms with six pumps in each room, having separate suctions and discharges connected with a separate hose to the dock. Each grade of oil is discharged directly to the tank without danger of mixing. The pumps used on this type of ship are somewhat smaller than those used on tankers carrying a single grade of oil. They are usually fitted with 8 inch suctions and 6 inch discharges. Since the cargo is valuable, a small suction line is usually provided in addition to the above for stripping the tanks dry. The oil saved by this method pays for the time required in stripping.

Some technical data on tank steamers should prove of interest. The question of tonnage is confusing to the average landsman. This is a term used to denote the hundredth part of the capacity in cubic feet of the combined spaces enclosed by the vessel, usually after making certain deductions. When measured below the upper deck, the tonnage based on the internal capacity of the ship is known as the *under deck tonnage*; when forecastle, poop, bridge house, deck houses, hatches, etc., are added to the foregoing, it is called *gross tonnage*, which in turn becomes the *net register tonnage*, after certain legal allowances have been deducted. The *gross registered tonnage* is obtained by dividing the number of cubic feet of capacity of the ship by 100. The *net registered tonnage* is obtained by dividing by 100, the capacity in cubic feet of the space available for cargo and passengers; this space being found by deducting from the entire capacity of ship, the space occupied by machinery, accommodations for crew and other housings designated by law. Displacement (also usually expressed in tons) is simply the weight in tons of the water pushed aside by the body immersed. All bodies upon immersion in a liquid displace a volume of the liquid equal in weight to the actual weight of the body immersed.

Voyage periods over the usual tanker routes are about as follows, over a yearly average: Tampico to New York, Philadelphia or Boston, 22 days; Tampico to West European ports,

•

58 days; New York or Philadelphia to English ports, Antwerp and Havre, 33 days. All of the above periods are for round trips and include time in port for loading and discharging. The question of lost time in port is one of great importance. When the daily cost of tank steamers is considered, it is obvious that every effort should be made to reduce the time of loading, discharging, taking on stores, etc.

The fuel consumption of vessels varies with the type of machinery. Modern ships with Diesel engines have been operated on 0.33 pounds of oil per indicated horsepower hour, although an average of 0.45 to 0.50 pounds is perhaps more representative. The ordinary type of steam-propelled vessels with Scotch marine boilers and reciprocating engines consume about 1.4 pounds of oil per indicated horsepower hour. It is probable that this figure will be improved in the next few years.

The harbor equipment necessary for the delivery of fuel oil from a terminal to the various points of consumption sometimes assumes large proportions. If a company bunkers many ships several bunkering barges of about 7,000 barrels capacity will be required. Since these barges have in general no means of propulsion, tugs are necessary to tow them around the harbor. The average barge carries about 7,000 barrels. It is usually 175 feet long, 30 feet in beam and has a depth of 9 feet. It is generally scow shaped and divided into four or six compartments. Some recent barges have a pump house amidships in which is located a 125 horsepower boiler with the necessary fuel oil burning equipment and the pumps used for discharging the cargo. The pumps are fitted with a 12 inch suction and a 10 inch discharge line with two hose connections on the deck. These barges can be pumped out in about five hours. In addition some companies have self-propelled barges for distributing oil in small quantities around the harbor. They are similar to the above except that they are boat-shaped, with finer bow and stern lines. They are fitted with gasoline or Diesel engines of about 300 horsepower, which give a speed of  $5\frac{1}{2}$  or 6 knots per hour.

All forms of oil transportation represent a special service

which requires a classification separate and apart from all other forms of transportation. It is practicable to operate pipe lines in only one given direction; a tank car can carry its load only in one direction. It must return empty, as must a tanker; although it leaves with a full cargo. This accounts for some of the expenses of the oil business which the general public cannot understand. Some companies have attempted to haul wheat or rice on the return trips of their clean ships, but this was found to be unprofitable. Other companies have hauled bulk molasses on the return voyages of their dirty ships. The expression "dirty ships" means ships that carry cargoes of fuel oil, crude oil, lubricating oil or gas oil. By the contra expression "clean ships" is meant ships carrying cargoes of gasoline or kerosene.



## CHAPTER XIX

### PACKAGES

Wooden barrels; petroleum cans; steel barrels.

Large quantities of petroleum products are sold in wooden barrels. For domestic consumption, burning oil and lubricants constitute the bulk of oil shipped in such containers. This is also true of exports, with the addition of considerable quantities of gasoline. Practically all refiners use wooden barrels to some extent. Some purchase their requirements. The large refineries, however, are usually equipped with complete plants for the manufacture of their own barrels.

In general, barrels are made from well-seasoned white or red oak. The standard list of Table 59 has been adopted by a committee of the cooperage firms.

Staves and heading may be purchased kiln dried and jointed (K.D. & J.) or air dried and listed (A.D. & L.). In the former case, they are ready for assembly into barrels, while the A.D. & L. stock will require kilns and a jointer shop for further preparation before use.

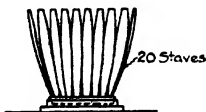


FIG. 205

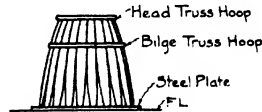


FIG. 206

Barrel staves in "raising block." Staves upended from "raising block."

The K.D. & J. staves are "set up" on a raising block by hand. They will average about 20 to the standard barrel. A temporary head truss hoop (a heavy iron ring) is first placed on the block and the staves wedged therein, with an appearance as shown in Fig. 205. The barrel is then up-ended and a bilge truss hoop applied, Fig. 206. At this point the assembly is

TABLE 59. STANDARD BARREL SPECIFICATIONS

No.	Size	Wood	Hoops	Hung	Coating	Use
1	50-52 gal.	$\frac{3}{4}$ -in. white oak, tight sap.	6-17 and 18 gauge.	2-in. bilge.	glue or silicate test (buyer's option).	Only for especially difficult wood alcohol and spirits.
2	do.	$\frac{3}{4}$ -in. white and chestnut oak.	do.	do.	do.	I.C.C.—10 specif. Inflammable oils with flashpoint above 20° F., viz., shellac, japan varnish, leather dressing and similar products.
3	do.	same except 1-in. heads.	6-16, 17 and 18 gauge.	do.	do.	I.C.C.—9 specif. Inflammable oils with flashpoint below 20° F., viz., naphtha, gasoline, benzine, ether, rubber cement or other products containing one of these as a body, Common oil barrel. Light lubricating oils; road oils, linseed oil, etc.
4	do.	$\frac{3}{4}$ -in. white and chestnut oak.	6-18 and 19 gauge.	do.	do.	Thin or penetrating oils, viz., turpentine, burning oils, dryers, cottonseed oil (cottonseed always in silicated barrels).
5	do.	chestnut oak, selected sound-sap stock.	do.	do.	do.	
6	do.	$\frac{3}{4}$ -in. red oak.	6-17 and 18 gauge.	do.	do.	I.C.C.—10 specif. Heavy inflammable oil products with flashpoint above 20° F., paints, heavy varnishes, etc.
7	do.	do.	6-18 and 19 gauge.	do.	do.	Common oil barrel. Heavy lubricating oils, black oil, etc.
8	55-60 gal.	$\frac{3}{4}$ -in. red oak.	6-18 and 19 gauge.	do.	do.	Common grease or glucose barrel. Oil soap, grease and oils that pour thick.

*Note:* If eight hoops or finished coating is desired, specify in connection with above numbers.

*Note:* For other sizes, merely specify size and numbers. For example: 32 gallon No. 3, 60 gal. No. 7, etc. Most shops can supply the following standard sizes: 5, 10, 15, 20, 25, 32, 40, 45, 52, 55, 60 gal. Odd sizes mean special work and higher prices—do not use them unless a standard size is impracticable.

steamed to render the staves pliable. Fig. 207 shows the Oram barrel steamer. Some of the larger Standard companies use a patented "steam wheel." This apparatus is a steel plate cylinder about 16 feet in diameter by 3 feet deep, arranged with a horizontal axis set in a steel frame. Revolving on the axis is a structural frame provided with compartments in which the assembled staves are placed. Openings at the floor level are left at either side in order to insert and to remove the barrels. Exhaust steam is introduced and the staves make a revolution in about 7 minutes in the hot vapors. This machine saves considerable labor in the handling of the barrels. About 20 pounds weight of exhaust steam per barrel are required in order to

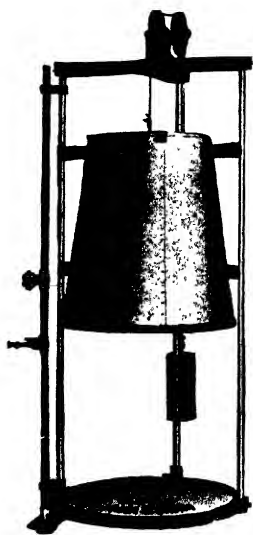


FIG. 207

Barrel steamer.

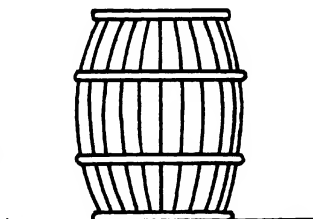


FIG. 208

Barrel with temporary truss hoops.

render the staves pliable. About six horse power is necessary to drive the wheel. The capacity of one wheel is from 120 to 130 barrels per hour.

After steaming, the staves pass to a windlass where a steel

cable is placed about the open ends of the staves and is drawn up by hand or by power. A second head truss hoop is now slipped over the ends of the previously flaring staves, and as the barrel comes from the windlass, a second bilge truss hoop is applied. If power driven, the windlass will consume about 2 horsepower. When operated by experienced men, power driven windlasses will handle from 135 to 140 barrels per hour.

The barrel with the four temporary truss hoops now presents the appearance shown in Fig. 208 and is ready for firing, which dries out the steamed staves and gives them a permanent set. Fig. 209 shows a firing device in common use. The Standard Oil companies have here again eliminated labor by the use of a patented "firing ring." The barrels are placed over oil fired burners on the ring, which revolves very slowly in a horizontal plane. As the barrel traverses the circle, it is thoroughly dried and set. Light fuel oil or gas is preferred for firing. From 7 to 8 gallons of fuel oil are consumed in firing 100 barrels. The speed of the ring is so adjusted that the output of the firing ring will keep the succeeding machines up to speed. As usually operated, from 130 to 140 barrels are fired per hour.

Now approaching its final shape, the barrel passes from the burners to the levelling machine. This machine vibrates and taps the staves until the ends of the barrel are level. At this point, or later as preferred by some, it passes to an auger for the boring of the bung hole.

At this stage, it is customary to drive up the truss hoops on the "truss hoop driver." The barrel is placed on the platen at floor level, the steel fingers are dropped over the head hoop and the platen raised by power, the operation being repeated for the

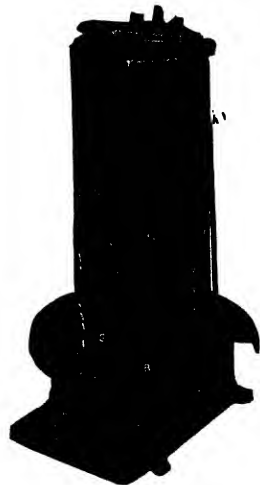


FIG. 209  
Barrel "fire pot."

bilge hoop. The barrel is then up-ended and the two remaining hoops are driven tight.

The barrel now goes to the crozer where it is placed horizontally and revolved against knives which chamfer the stave ends and cut the croze. A section of the stave after crozing is shown in Fig. 210



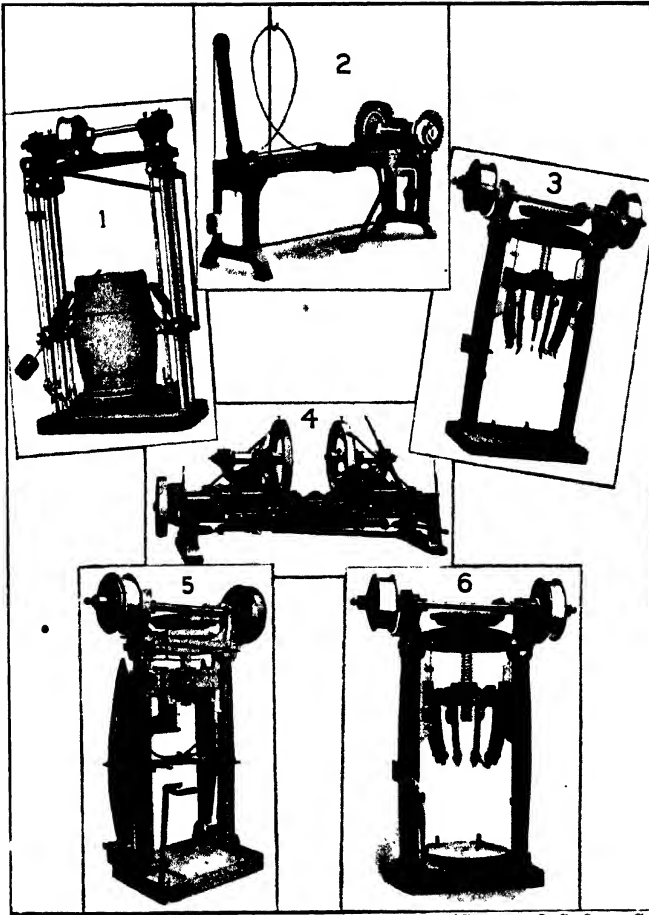
FIG. 210  
Stave with croze.

The head truss hoops are now removed by hand or by machine, and, while held by the bilge hoops, the barrel is placed in the heading-up machine. The staves spring apart at the ends when the head truss hoops are removed, allowing the head to be inserted in the croze. The machine then draws the staves together and the final thin hoop is placed over them to hold the head in place. In large factories, it is customary to use two heading-up machines for each set of the other machines. One head is placed on the first machine while the other is applied on the second.

At this point the barrels are carefully inspected for worm holes and pin holes. Such imperfections are plugged or the barrel is sent to a cooper for attention.

The final thin steel hoops are now applied and driven by the hoop drivers. These machines are similar to the truss hoop drivers previously mentioned. Two drivers are required to keep pace with the other operations. The barrel is now a complete assembly and is ready for preparation. Its appearance and dimensions are shown in Fig. 212.

As preparation for service, the inside of the barrel is given a coating of glue. It is customary first to use a test coat of about  $\frac{1}{4}$  pound per barrel. The hot glue is introduced through the bung and the barrel is rapidly spun. A rubber plug is then inserted in the bung hole and a slight pressure is built up to disclose imperfections. The barrel is then placed bung down on a slowly moving conveyor and allowed to drain, the speed and length of the conveyor being such as to permit of drainage for about 20 minutes. The barrels are then stacked on end and allowed to age for not less than one week and preferably for two weeks.



(Courtesy J. S. Oram Co.)

FIG. 211

Barrel factory machines.

1. Levelling machine.
2. Single end power windlass.
3. Truss hoop driver.
4. Crozing machine.
5. Heading up machine.
6. Thin hoop driver.

They are then ready for the second glue coat. Practice varies but from 0.7 to 0.8 pounds of glue per barrel is a fair average

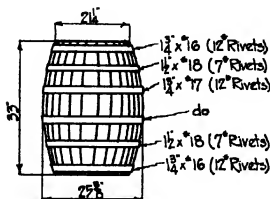


FIG. 212

Finished barrel.

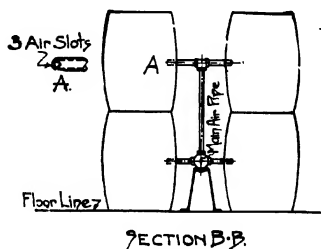


FIG. 213

Barrels piled two high for air blast.

for the second coat. It is applied as above, but is usually set by means of a cold air blast. The barrels are placed on end, one or two high, with the air blast pipes inserted in the bungs (Fig. 213). From 10 to 15 cubic feet of air per minute per barrel at a pressure of from 4 to 6 ounces are the usual requirements. The time of drying will vary from 4 to 8 hours depending upon the humidity.

The process of gluing barrels is one requiring careful workmanship and supervision, as a non-uniform coat, or drops of moist glue, will result in trouble after filling.

The thin hoops mentioned above are punched, riveted and expanded on special machinery. One double end punch, two riveting machines and three expanders will accommodate one set of barrel machines, supplying sufficient hoops for from

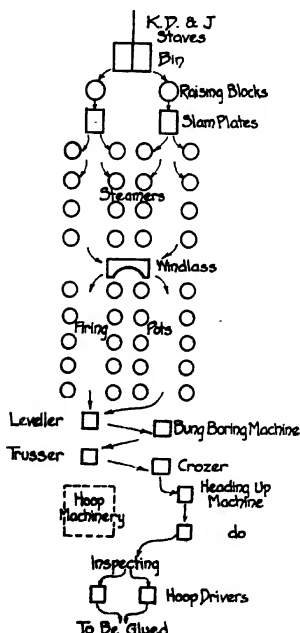


FIG. 214

Floor plan of barrel factory.

1,200 to 1,400 barrels per day. Three riveters will accommodate two sets of barrel machinery. Three expanders are necessary in any event, one for each of the three different sized hoops. One set of three expanders, however, will accommodate two sets of barrel machinery.

Fig. 214 shows the general arrangement of a barrel factory. The machines are operated in a set. Since if one machine stops the entire series is thrown out of commission, individual power drive is not advisable. Exhaust steam is used so extensively that simple steam engines with line and secondary shafting may be economically used.

For one set of machines, the power requirements are about as follows:

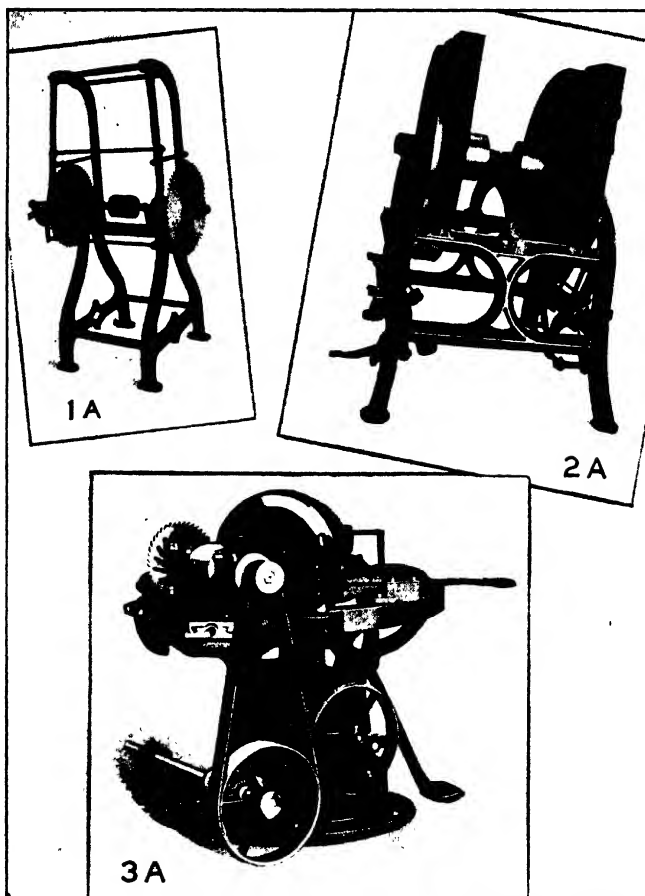
	Horsepower
1 windlass .....	2
1 leveler .....	2
1 boring machine .....	1
1 truss hoop driver .....	6
1 crozer .....	6
2 heading-up machines .....	10
2 hoop drivers .....	10
1 double punch .....	6
2 riveters .....	4
3 expanders .....	6
Total.....	53

If the steam wheel and firing ring are used, 12 additional horse power will be required. The above figures do not include the necessary power for repair shop machine tools, or for fans and conveyors.

A force of about 65 men will be required to operate one set of machines. If the steam wheel and the firing ring are used, this force may be reduced by 8 or 10 men. A yard crew for handling staves and a crew of 25 or 30 men for preparing and stacking the barrels will also be necessary. The capacity of the plant is about 135 barrels per hour or 1,250 per day.

The weight of the finished barrel of the size shown in Fig. 212 is from 90 to 95 pounds. Half barrels and quarter barrels





(Courtesy J. S. Oram Co.)

FIG. 215

Jointer shop equipment.

1. Equalizer.
2. Double jointer.
3. Heading rounder.

are also manufactured. These smaller barrels require a different set of machines, similar in type but of smaller dimensions. The standard barrel has a nominal capacity of 50 gallons. It usually has from 2 to 3 per cent. excess capacity. Barrels will roll easily but not too rapidly on an inclination of 16 inches per 100 feet when empty and on one of 12 inches per 100 feet when filled.

Mention has previously been made of the use of air dried and listed staves. This type of stave can be bought for less than the kiln dried and jointed type but will require kilns and a jointer shop, and additional yard space. For large plants, greater economy will probably be attained by using the A.D. & L. staves.

The A.D. & L. staves and heading are loaded from the yard into cars provided with steel racks, and holding from 2,500 to 3,000 staves each. A kiln capacity of 20 cars will, therefore, accommodate from 50,000 to 60,000 staves per charge. A kiln cycle requires about 4 days. The daily output of one kiln will furnish enough staves to make from 650 to 750 barrels per day. Two kilns will thus accommodate one set of barrel machines with sufficient reserve to handle the heading.

A 20 car kiln is 15 feet wide and 120 feet long. Kilns are built of brick, tile or other material of good insulating properties. Steam coils designed for a pressure of 100 pounds per square inch and aggregating 1,200 square feet of surface are placed on the floor under the car tracks. Ventilators of ample capacity are installed in the roof. The temperature is raised to 100 degrees F. at the start of a charge and gradually increased to from 140° to 150° during the four days. After drying, the cars are removed to a cooling shed from which they enter the jointer shop.

In the jointer shop, the rough staves and heading are prepared for assembly into barrels. The staves first pass to the equalizer, where two cut-off saws on one arbor give them a uniform length. 1,200 staves per hour (equivalent to 60 finished barrels) is a fair average throughput for the equalizers. The

next step is shaping the stave to its finished form. This is done on the jointers. This machine is made in two types, the single wheel jointer and the double wheel type.

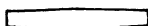


FIG. 216

Shape of barrel  
stave.

The revolving wheels carry knives against which the staves are pressed, giving them the shape shown in Fig. 216.

In addition to preparing the staves, the jointer shop must handle the heading. The heading material first passes to a heading jointer similar in general construction to the stave jointers but equipped in addition with doweling attachments. The jointed material is then doweled to form a roughly square piece. The heading jointers will handle the equivalent of 150 heads (sufficient for 75 barrels) per hour, each. After doweling, the heads pass through a planer of the usual wood working type and then to the so-called heading "rounder." This machine cuts the heads to shape and also bevels the circumference to fit the croze of the barrel. The machine has a capacity of 300 heads or 150 barrels per hour.

The auxiliary equipment of the jointer shop includes an efficient exhaust system for removing scraps and sawdust which may later be used for fuel.

The following table summarizes the requirements of the jointer shop based on a capacity of 1,250 barrels per day or for one set of machines in the barrel factory proper:

	Horsepower
2 equalizers .....	6
4 double jointer wheels .....	32
2 heading jointers .....	8
1 planer .....	4
1 heading rounder .....	5
Exhaust system .....	10
Total connected load.....	65

As in the previous case steam engine drive is recommended on account of the large demand for exhaust steam for steaming and drying barrels.

The labor requirements will be about 20 operatives in the jointer shop besides a variable crew for handling material to and from the kilns.

Where jointer shops are included in barrel factory installations, it is customary to provide a separate boiler house adapted for burning wood, distinct from the refinery boiler house. The steam lines may be connected to the refinery mains for emergency service. The jointer shop refuse will be ample fuel to operate the entire barrel factory. The exhaust steam from the engines will supply the barrel steamers, but in cold weather a reducing valve between the high and low pressure mains may be necessary for heating the buildings. The vertical water tube boiler is preferred by most companies for burning wood refuse from a jointer shop. .26 square feet of grate area per boiler horsepower with from 0.7 in. to 0.8 in. of draft are recommended. Ample Dutch ovens are usually installed, the wood feeding into their tops from bins overhead. Stack sizes from 20 to 25 per cent. in excess of those used for coal-burning boilers have proved satisfactory. Spark arresters are a necessary adjunct to each chimney.

Steel barrels are in favor with many refiners in preference to the wooden product. The advantages claimed are longer life, elimination of gluing and cooperage expense, popularity with the trade, and freedom from the possible contamination from improperly applied glue coats. The initial investment is higher than that for wooden barrels. The weight of a steel barrel designed to meet I.C.C. specifications and provided with heavy rolling hoops to insure long service is slightly in excess of that of a standard wooden barrel.

The capacities, dimensions, weights and carload quantities of the steel barrel, shown in Fig. 217, are given in table 60, on page 372.

The manufacture of steel barrels requires extensive plant equipment and quantity production is necessary for economy. For these reasons refiners have not undertaken this work and the methods of manufacture will not be discussed.



Patented June 16, 1909  
Foreign Patent 12, 1911  
Pierce, Fennell & Smith

FIG. 217  
"Draper" steel  
barrel.

Tin cans are largely used in the industry for various products. The 5-gallon can is practically standard for exports of naphthas and kerosenes. This can is made from I.C. tin plate weighing 0.491 lbs. per square foot. The dimensions of the finished can are  $9\frac{3}{8}$  inches by  $9\frac{3}{8}$  inches by  $13\frac{3}{4}$  inches, and its weight is  $2\frac{3}{8}$  pounds. For lubricants, 2-gallon and 1-gallon cans are also in use.

TABLE 60. STEEL BARREL SPECIFICATIONS

## BLACK BARREL

Gauge	Capacity			Dimensions			Weight		Average Car Load		
	U. S. Gal.	Imp. Gal.	Liters	Out-side Dia. In.	H'ght In.	Cu. Space Ft.	Lbs.	Kilos	36 Ft.	40 Ft.	50 Ft.
<sup>a</sup> 16	55	45¾	208	25	34¾	12½	92	42	180	200	250
<sup>b</sup> 14	55	45¾	208	25	34¾	12½	107	49	180	200	250
<sup>a</sup> 14	110	91½	416	31	42	23½	168	76	80	89	112
<sup>b</sup> 12	110	91½	416	31	42	23½	229	104	80	89	112

## GALVANIZED BARREL

<sup>a</sup> 16	55	$45\frac{3}{4}$	208	25	$34\frac{3}{4}$	$12\frac{1}{2}$	100	45	180	200	250
<sup>b</sup> 14	55	$45\frac{3}{4}$	208	25	$34\frac{3}{4}$	$12\frac{1}{2}$	115	52	180	200	250
<sup>a</sup> 14	110	$91\frac{1}{2}$	416	31	42	$23\frac{1}{2}$	180	82	80	89	112
<sup>b</sup> 12	110	$91\frac{1}{2}$	416	31	42	$23\frac{1}{2}$	244	111	80	89	112

<sup>a</sup>—Complies with I. C. C. Specifications No. 5.

<sup>b</sup>—Complies with I. C. C. Specifications No. 5-A.

Many of the larger oil companies use cans in sufficient quantity to warrant the installation of a department for their manufacture. A set of standard 5-gallon can making machines has an output of 5,000 finished cans per day. This figure may be taken as the minimum quantity which may be economically manufactured. For lesser quantities the requirements are usually purchased ready for use.

An outline of the manufacturing process is as follows.<sup>1</sup> The

<sup>1</sup> The author is indebted to the E. W. Bliss Co., of Brooklyn, N. Y., for data on the manufacture of cans.

sheets are first introduced to the top and bottom press and pressed into the shape shown in Fig. 218. If the tops are of elaborate design, separate dies and punches may be used for the tops and bottoms. Otherwise one machine may be used to perform both operations by providing a removable filler hole punch which is removed when making the bottoms. Where a large quantity of cans is to be produced, automatic machines may be used.

The body of the 5-gallon can is made in two pieces, which are trimmed from the blank by the trimming press. After trimming, the blanks pass to the hemming machine. The hemmed blanks are then transferred to a press where the panels are stamped, hooks are formed



FIG. 218

Can bottom.

on the edge and the sheet bent to an angle. The appearance of the half body is shown in Fig. 220. The two half bodies as they come from the above operation are loosely hooked together by hand and the two corner seams are pressed tight in the horn-  
ing press.

The tops and bottoms are attached to the body by a squeezing machine. Fig. 221 shows a sectional view of the can with ends attached. The seams are then rolled by machine to insure tightness, after which the can is ready for soldering. In small plants, the corner seams are generally hand soldered. When large quantities are to be manufactured, the automatic machine shown in Fig. 222 may be used. In this machine the cans are placed on conveyors, one seam is passed through acid and solder baths, and the can is then turned and the process is repeated for the opposite corner. The seams are automatically wiped and delivered ready for soldering the ends. End dipping furnaces are in general use for small plants. For larger installations, automatic machines are obtainable, similar to the ones used for corner soldering.

Screw tops and caps are pressed and the threads rolled thereon. A tagger's tin base is usually introduced between the screw top and can body. This base thoroughly protects the



Fig. 1



Fig. 2



Fig. 4



Fig. 5

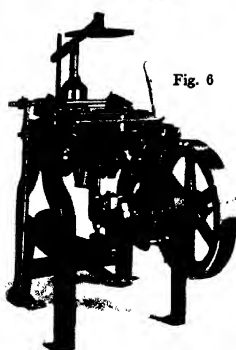


Fig. 6

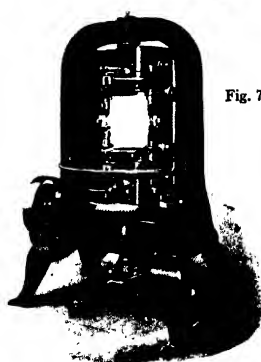


Fig. 7

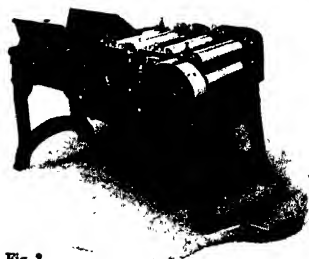


Fig. 3

FIG. 219

Machines for manufacture of 5 gallon cans.

1. Top and bottom press.
2. Body and blank trimming press.
3. Hemming machine.
4. Hook forming press.
5. Horn press.
6. Squeezing machine.

contents. It is punched out by the consumer. In addition, stamped tin handles or wire handles with clips are soldered to the tops prior to their assembly with the body.

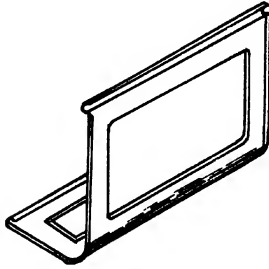


FIG. 220  
Half body.

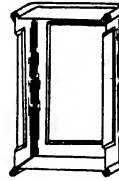
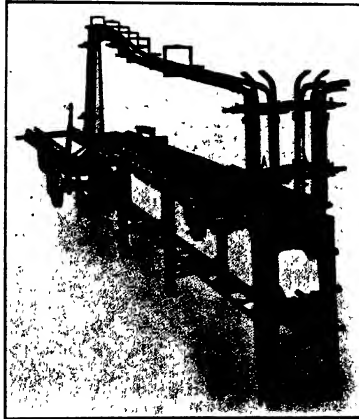


FIG. 221  
Section of can with ends at-  
tached.

The following tabulation gives, in order, the necessary equipment and power requirements for a plant manufacturing 5,000 five-gallon cans per day:



(Courtesy E. W. Bliss & Co.)

FIG. 222

Automatic soldering machine.



## Cans

	Horsepower
1 press with top die .....	3
1 press with bottom die .....	3
1 body blank trimmer .....	4
1 hemming machine .....	2
1 panel press with hook and bending attachment .....	4
2 double horn presses for setting corner seams .....	4
2 squeezers, attach heads .....	4
1 seam roller .....	3
6 dipping furnaces .....	-

## Screw Tops

3 presses .....	3
1 thread roller .....	1
1 crimping machine for tagger's tin top bases .....	1

## Tin Handles

1 punch press with die and punch .....	1
1 handle hemming machine .....	1
1 forming press with stamping die .....	1½

The total connected load is 36½ horsepower, with a load factor for this class of work of 75 per cent.

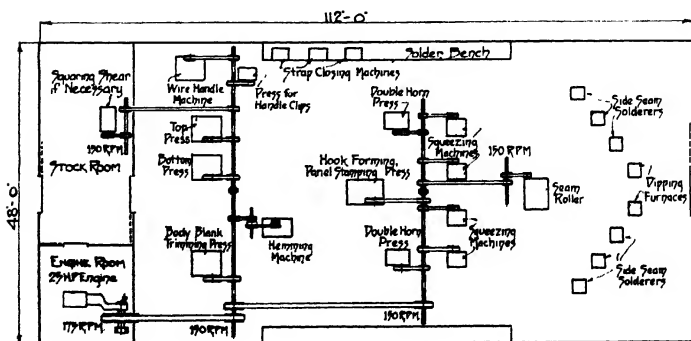


FIG. 223

General arrangement of machines for manufacture of 5 gallon cans.

The general arrangement of a department as above described is shown in Fig. 223. The floor space occupied exclusive of that for storage of plate and cans is approximately 5,500 square feet. Can departments lend themselves readily to multi-story building construction if due consideration is given to the floor loads. Tin plate in storage presents an excessive load. For that reason it is stored on ground level floors or in basements and is moved by truck and elevator as required.

The one- and two-gallon cans follow, in general, the same process of manufacture as the larger size. The bodies may, however, be formed of one piece, simplifying the procedure. Automatic machines are available which will take the one piece body blank and turn out the body fully formed and with the seams pressed.

For export shipment the filled cans are placed in wooden cases. Data on these cases are as follows:

#### TABLE 61. SPECIFICATIONS OF WOOD CASES

##### THREE-EIGHTHS INCH CASE (REGULAR EXPORT SIZE)

One case containing two five-gallon cans:

Thickness of sides, tops and bottoms .....	$\frac{5}{8}$ in.
Thickness of ends .....	$\frac{3}{4}$ in.
Measurements: 10 $\frac{1}{2}$ in. by 20 $\frac{1}{2}$ in. by 14 $\frac{1}{4}$ in.	
Tare weight: 16 $\frac{1}{2}$ pounds. (Case containing two cans.)	
Contents: 1.815 cubic feet.	

##### FIVE-EIGHTHS INCH CASE (HEAVY)

One case containing two five-gallon cans:

Thickness of sides, tops and bottoms .....	$\frac{5}{8}$ in.
Thickness of ends .....	$\frac{3}{4}$ in.
Measurements: 10 $\frac{1}{2}$ in. by 20 $\frac{1}{4}$ in. by 15 $\frac{1}{2}$ in.	
Tare weight: 22 pounds. (Case containing two cans.)	
Contents: 2.008 cubic feet.	
(Steamship companies would figure the cubical measurements as:	

$$\frac{11 \times 21 \times 15}{1728} = 2.01 \text{ cubic feet.}$$

## SEVEN-EIGHTHS INCH CASE (EXTRA HEAVY)

One case containing two five-gallon cans:

Thickness of sides, tops and bottoms .....  $\frac{7}{8}$  in.

Thickness of ends ..... 1 in.

Measurements: 11 $\frac{7}{8}$  in. by 20 $\frac{3}{4}$  in. by 15 $\frac{3}{4}$  in.

Tare weight: 29 pounds. (Case and two cans.)

Contents: 2.1513 cubic feet.

(Steamship companies would figure:

$$\frac{11 \times 21 \times 16}{1728} = 2.14 \text{ cubic feet.})$$

## CHAPTER XX

### THE POWER PLANT AND BOILER HOUSE

**Steam requirements—Notes on boiler houses and steam distributing systems—Use of superheated exhaust steam for distillation—Electrical requirements.**

As the previous chapters have shown, refinery work requires an abundance of steam; while the amount of mechanical energy necessary is surprisingly low when the magnitude of the investment and number of employees are considered. In the early days of refining, little attention was paid to this subject. As plant expansions required more steam, more boilers were installed. Since the pressures in use were low compared with those of present day practice, and the distributing systems were often inadequate, the usual expedient was the erection of a new boiler house adjacent to the new point of consumption. Recently, however, the low efficiencies of these installations have begun to be realized and several of our largest plants are changing or making plans to change to modern systems with central boiler plants and power houses. Such plants equipped with every convenience and labor saving device, and distributing steam at high pressures and electricity at high voltages, offer great opportunities for the application of sound engineering. The economical limit of size of refinery central stations has not been reached. Central plants serving areas well over 500 acres are now in operation, and central stations other than those in oil yards are distributing steam to points over a mile distant.

Before proceeding further with the detailed discussion, it is advisable to establish some criterion for the total steam requirements of an oil refinery. The following are typical examples of the steam consumption in pounds per barrel of crude run :

TABLE 62. EXAMPLES OF STEAM CONSUMPTION

Complete lubricating refinery .....	450 to 460
Skimming, Mid-Continent crude .....	180
Semi-lubricating, Texas crude .....	200
Skimming, light Mexican crude .....	190
Skimming, Louisiana crude .....	144 <sup>1</sup>
<sup>1</sup> Electrical power purchased.	

The above figures include all steam used in process work and also that necessary for generating mechanical power. It is obvious that the power house capacity for a complete refinery where steam is used extensively in the stills, and also in the wax, filter, compounding and other departments, is greatly in excess of that required for a skimming plant. In the latter, since cracking of the oil in the stills is not objectionable, and since the numerous re-running and finishing steps are not taken, a much smaller quantity of steam will suffice.

The amount of steam used is also dependent upon individual preference and upon the exact routine followed. For instance, when distilling, some refiners may be able to make closer separations than others, which will reduce the amount of re-running and consequently the steam consumption. As a general guide, however, the following table is offered showing the pounds of steam required per barrel of crude for various methods of operation:

TABLE 63. STEAM CONSUMPTION. VARIOUS TYPES OF REFINERIES

Paraffine base oils, complete refinery, all products finished .....	500
As above, eliminating compounding and package shipments .....	450
Complete asphalt refinery .....	360
Complete heavy lubricating oils, such as Gulf Coast.....	250
Semi-complete, mixed base oils, wax plant included .....	250
Skimming plants, 50 per cent. overhead .....	175
Skimming plants, 30 per cent. overhead .....	150

As an example, a 1,500 barrel plant of the first type would require 750,000 pounds of steam daily, the equivalent of about 1,042 boiler horsepower.

For a detailed treatment of boiler house design the reader is referred to any of the standard works on the subject. Only the special considerations involved in oil refinery work will be

discussed herein. The question of variation in load is important for all plants. In an oil refinery the load is remarkably constant. Practically all of the work necessitates 24-hour operation, the decreased load from the shops and other day work departments being largely balanced by the night lighting load. This fact would seem to warrant the operation of the boilers at a fairly high overload except for one consideration. Fires in an oil refinery are fought to a large extent with steam which is blown into the tanks to displace inflammable vapors in all threatened portions of the yard. This procedure is also customary during thunder storms; and this increased load is of no small importance at the boiler house. For this reason, considerable reserve steam capacity is highly desirable, without the necessity of waiting to bring a spare unit up to pressure and onto the line.

About one hundred and twenty-five per cent. of the nominal boiler rating is a suitable rate of operation which will combine good efficiency with plenty of reserve capacity for emergencies. In the above example, boilers of nominally 800 horsepower capacity operated at 130 per cent. of rating would take care of all normal loads. Since one or two spare units are advisable for breakdown service, five 200 or four 250 horsepower units would be satisfactory. While boiler units are increasing in size, care should be exercised not to choose units so large that the percentage of idle equipment represented by the spare boilers becomes excessive. With the normally steady plant load and with the conservative overload recommended, not too much idle equipment should be contemplated.

Very few manufacturing plants can offer the opportunities presented by an oil refinery for obtaining hot boiler feed water. The usual practice is to provide an insulated hot water feed tank at the boiler house and to pass the feed water by means of the well or service pumps over those oil still condensers which offer the hottest vapors. Feed water temperatures of from 125° to 150° F. may be attained by this method, the former figure in the case of skimming plants and the latter in complete refineries where the heat from the vapors of the heavy lubricating cuts may be utilized.

Previous mention has been made of the hot flue gases from the stills. This waste heat may be advantageously utilized for increasing the temperature of the feed water. For this purpose the ordinary form of economizer is often installed in the flue leading from the still battery to a central stack. The boiler feed pumps drawing from the tanks containing the feed water, already heated by the oil vapor condensers, are then arranged to discharge the water through one or more economizers connected in series or in parallel before delivering it to the boilers. The temperature of the feed water entering the boilers can thus be raised to 250° or 350° F. by means of a simple and reliable system. Heating the feed water from 125° to 250° F. results in a saving of fuel of 11 per cent. If the temperature is raised to 300° F. the saving becomes 16 per cent. For the plant of the previous example, assuming an evaporation of 10 pounds of water per pound of coal, these figures will represent a fuel saving of 1,505 and 2,190 tons per year respectively.

In the older refineries, low boiler operating pressures, of from 60 to 100 pounds, are usually encountered. For process work, low pressures are satisfactory and since the boilers were usually adjacent to the point of consumption, the system was acceptable. With the central station system arranged for extensive distribution over wide areas, however, higher operating pressures, of from 150 to 175 lbs., are much more economical. For economical turbine and engine operation as well as for economy in transmission, superheaters are largely used. A superheat of 100° is customary.

High steam pressures for use in stills are not necessary. Gauge readings back of the control valves on the sprays rarely indicate more than 5 pounds. Plenty of volume for agitation is all that is required. Most stillmen have a decided prejudice against less than sixty pounds on the still headers but no logical reason can be given why fifteen or twenty pounds will not suffice. Wet steam is objectionable. If it were not for this reason exhaust steam would be satisfactory. Three and possibly more of our largest refineries are overcoming this objection and

utilizing exhaust steam in the stills by superheating the exhaust steam prior to introducing it into the stills. From 15 to 20 pounds back pressure is carried on all turbines, engines, pumps and compressors. The exhaust steam is collected from all points of production, and is superheated in separately fired apparatus. As the quantity of exhaust steam is rarely sufficient to meet the demands of the stills, a make-up from the high pressure system is provided. With the old saturated steam systems the temperature of the oil in the stills is generally above that of the entering steam. As a result the steam abstracts heat from the oil and is in effect superheated within the still. The low efficiency of the oil still was discussed in Chapter VII. The still is equally inefficient as a steam superheater. With the steam superheated independently to 400° or 500° F. not only a lower fuel consumption but also a better rate of distillation in the stills is obtained.

Since the average refinery will not produce sufficient exhaust steam for the stills, it is apparent that when exhaust steam is used the economy of prime movers and pumps is of no moment. In fact, each piece of equipment operates as a reducing valve, utilizing the steam but passing it along for further use. There are unfortunately no available tests to disclose the exact economy of the superheated exhaust steam system. Any analysis should cover the saving in fuel due to superheating in an efficient apparatus rather than in the still, the saving in time of distillation or, as better stated, the increased capacity with a given still installation (variously estimated at from 8 to 12 per cent.), and the decreased overhead cost resulting from a lower first cost of prime movers and pumps. Balanced against this is the cost of the exhaust mains and the separately fired superheater. In this respect each refinery presents its own problem which, however, may be analyzed with reasonable accuracy.

The steam distribution system of refineries is one which only too often receives insufficient attention. Accurate estimates of the steam consumption for the various departments are not difficult. A forecast of probable expansion offers more of a problem. Changes in methods of refining often result in more



rapid growth in some departments than in others. The following table may be used as a guide in laying out the steam mains:

TABLE 64. STEAM CONSUMPTION BY DEPARTMENTS

Department	Steam Required,	
	Lbs per Day	Per
Stills .....	120,000	1,000 barrels of charging capacity.
Treating dept., light oils .....	5,000	1,000 barrels treated.
Treating dept., lubricating oils ....	10,000	1,000 barrels treated.
Wax plants .....	750	100 barrels wax distillate pressed.
Filter houses .....	1,000	100 barrels filtered.
Compound houses .....	7,000	1,000 barrels tank capacity.

The figure for the stills will cover complete lubricating refineries and may be reduced 60 per cent. for skimming plants. The above table cannot be reduced directly to the steam consumption for any one unit over a day's operations but rather takes into consideration the idle time and varying steam consumption of the various units, allowing sufficient leeway for an occasional peak draft by any one piece of equipment. It will be found satisfactory for plants of from 10,000 to 15,060 barrels per day capacity. For larger plants with more units, the figures may be reduced about 10 per cent. and, vice versa, for smaller plants, they should be increased in the same ratio.

For high pressures, from 150 to 175 pounds, and moderate superheat, present engineering practice recommends steam velocities of from 10,000 to 12,000 feet per minute for outside distribution. For small plants operating at from 80 to 100 pounds pressure, 7,000 feet per minute is recommended. The maximum area for which these lower pressures will give economical distribution is in the neighborhood of 40 acres. In designing the mains, a careful forecast of future conditions is necessary. The principle outlined in Chapter VI, of designing the general arrangement of the plant for the greatest capacity ever probable and then so arranging departments that they are convenient one to the other and to the central power house; and then in the future to "grow out"; is particularly applicable to the matter of steam distribution.

The selection of steam generating equipment is subject to one or two conditions worthy of mention. For the small skimming plant of uncertain life, boilers of low first cost and good salvage value and portability are recommended. Steam generation, however, is one of the big items of refinery expense and for all complete refineries or those of long anticipated life, economy of operation (with due regard to the influence of first cost on interest and depreciation charges) is of prime importance and the best type of water tube boilers (with stokers, if coal fired) are to be recommended.

The question of coal vs. oil firing in refinery boiler houses, and in fact for all refinery work, is of interest. A refinery always has stocks of fuel oil and in certain locations there is no argument in favor of coal, the problem being a simple financial one. In other refineries adjacent to coal fields, there is little argument for oil. Many plants are so located that it is sometimes more economical to burn oil and at other times coal. Such refineries should determine the prices at which economies are equal and then be in a position to use either fuel. For a detailed discussion of the theories of combustion and of engineering practice with the two kinds of fuel, the reader is referred to standard text books on power houses. Very little is available on the technique of furnace design adapted to quick changes from one fuel system to the other. Until recently it was believed that a combination furnace did not lend itself to good efficiency for one fuel if designed for the other. Tests are now reported where the results are practically equal to the best practice on either fuel, in properly designed furnaces using either coal or oil at will. Fig. 224 shows a furnace so arranged that the stokers may be covered with ashes and brick, the burners inserted and the unit changed from coal to oil in a very few hours. Note that the usual bridge wall has been lowered and moved back, making one large combustion chamber for either the stoker fires or the back shot oil burners.

The electrical or mechanical power requirements for a refinery, as above noted, are relatively small. A small skimming

plant with steam driven pumps will have very little use for electric power with the exception of that used for lighting. The complete refinery, however, will use electricity to a large extent in its wax, filtering, case and can and compounding departments. not to mention the probably rather complete shops.

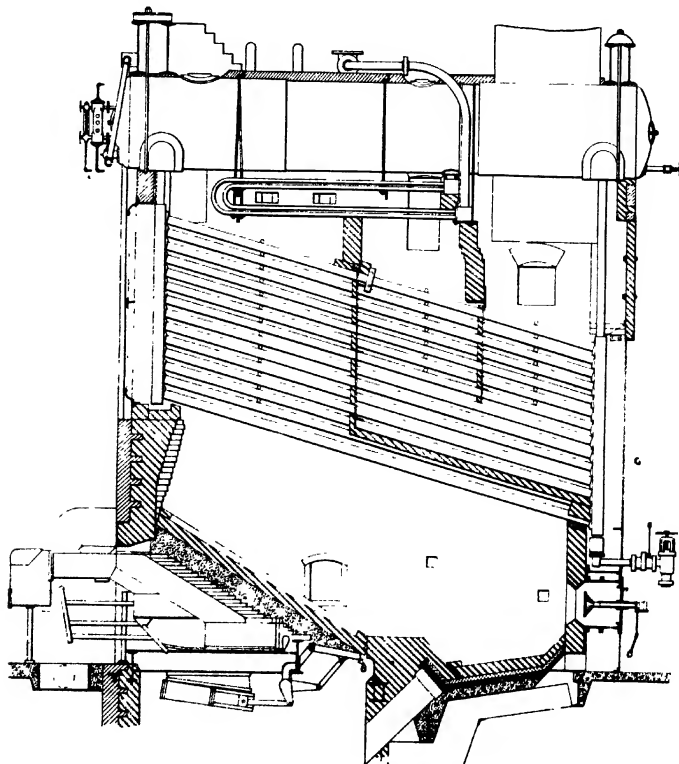


FIG. 224

Babcock and Wilcox boiler with combination furnace arranged for either coal or oil burning.

The question of electric drive for oil pumps is discussed more fully in Chapter XXII and the discussion of the various departments which follows assumes that direct steam or engine driven

pumps are used to take advantage of the exhaust steam therefrom.

The electrical load in wax plants will consist of chiller and press conveyor drives, elevators, press plate repair machinery, and often the drives for such pumps as sweaters, circulating water and brine. The total connected load for wax plants of 1,000 barrels daily wax distillate pressing capacity will be about 150 horsepower, and this ratio will hold for larger plants. The load factor may be taken at 60 to 70 per cent. The smaller plants will require a slightly higher electrical allowance; from 18 to 20 horsepower per 100 barrels being a safe figure. The power factor, if A.C. current is used in a plant of this kind, will be only fair. Motors for chillers and wax conveyors must have excess emergency capacity. Brine and circulating pump motors are capable of much better results. In connection with chiller and conveyor drives, one motor of say one and one-half times the capacity of the total load will yield a better power factor than individual motors; which, if used, should be those rated at about twice the individual loads to meet a possible emergency. The actual power factor for such departments will vary greatly and depends largely on the skill displayed in the selection of motor sizes.

Filter plants will require electric motors for clay elevators and conveyors, rotary kilns and coolers. The total load for such plants may be expressed in units of the clay charging capacity. For plants of 750 tons and upwards, 7.5 to 8 horsepower per 100 tons of clay charging capacity will cover the requirements. For smaller plants, an increase of 25 per cent. is advisable. The load factor in this department will be 55 to 65 per cent. A better power factor is possible than in wax plants, on account of the steady uniform kiln load.

Case and can manufacturing departments will furnish a steady day load. A total connected load of 7 horsepower per 1,000 average sized cans and 5 horsepower per 100 boxes or cases will cover this class of work. The load factor may be assumed fairly high, about 75 per cent. being recommended.

Chapter XIX discusses the power requirements of such departments in greater detail.

In compounding and barrelling departments, motors are usually adopted for barrel, case and can conveyors. This load is small and depends so much on local conditions that no general figure as to power consumed is of value.

Lights for yards and buildings will require considerable electrical energy. In large refineries, this load will be compensated for in part by the suspension of work in such departments as the shops and case and can departments. This fact, however, should not influence the selection of generating equipment, as occasions will arise where night work in the above departments is necessary. An allowance of 0.8 watts per square foot of buildings will cover the interior lighting requirements for average refinery conditions. Still and condenser lighting will consume about 0.5 K.W. per 1,000 barrels of charging capacity. Nitrogen-filled series lighting is largely used for yard purposes. A figure of 0.4 K.W. per acre for the refinery proper will cover its requirements. Areas reserved for tank farms are rarely illuminated. Special points which will require attention are the docks, loading racks and agitators.

The refinery shops (see Chapter XXII) furnish a considerable portion of the day load. This load is easily determined after the selection of the shop equipment is made. In addition, electrical power is often used for isolated pumps, water pumps (both service and fire), coal crushers and conveyors, if installed, economizer drives and like purposes.

These variations render a figure for generating capacity based on the throughput of small worth, and each case should receive a careful individual analysis.

Direct current is recommended only for those plants using electricity for lighting with only a small mechanical load as in skimming plants. For plants operating many motors, alternating current is preferable. Polyphase constant speed A.C. motors are simpler and more reliable than the D.C. type and (of still greater importance) do not present the fire risk of the lat-

ter. Alternating current may be distributed over wide areas at a high voltage with consequent economy. For small plants of 50 to 100 acres, 440 or 550 volt distribution is often used. For larger areas, 2,200 volt current is recommended. The frequency and phase of the system should correspond with that of the commercial central station if breakdown service is desired. Otherwise 60 cycle 3-phase current is the usual practice for modern equipment.

An electrical system of any size should be selected with the advice of experts, as many of the factors (such as overall power factor, location and design of transformer stations and selection of economical circuits) are important. These subjects are beyond the scope of this volume.

The selection of the prime mover for the generating sets is influenced by the policy adopted with respect to the use of steam. If live steam is to be used in the stills, an engine or turbine of good economy, arranged to run condensing, is suitable. However, the exhaust steam is usually of value in tank and building heating and therefore the above method of operation should be balanced against apparatus of lower first cost and lower economy, from which the available exhaust steam may be utilized. When exhaust steam is superheated and used for oil distillation there is no object in economy of steam consumption by the prime mover, and turbines with a high water rate are acceptable. In all cases reliability is of prime importance.

## CHAPTER XXI

### ACID RECOVERY

Acid separation—Pan and still system—Recent modifications—Chemical Construction Company's system—Simonson-Manitus process.

The problem of the disposal or recovery of spent acid left from the treatment of petroleum products is one of the most vexing to the refinery management. For a skimming plant, treating only light products, the complications are not great. The amount of acid used is comparatively small, the sludge is easily handled and the spent acid is usually wasted. In locations where stream pollution must be avoided, it is possible to control the discharge of spent acid so that it will enter the waste system with the alkali wash water, thus being wholly or in part neutralized. Moreover, it is greatly diluted with the general refinery run-off. Under this condition, very little trouble will be experienced except in extreme cases.

The acid sludge from the treatment of lubricating products causes greater difficulty. As drawn from the agitator, the sludge is a dark, viscous, tar-like liquid. It contains acid, oil and digested asphaltic bodies. This sludge must be separated into parts in order that the acid content may be recovered. Separation is performed in tanks with sloping or conical bottoms, each designed to accommodate the sludge from a lubricating agitator batch as shown by Fig. 225. About one-third excess capacity in the tank or kettle is advisable. Lead linings are necessary and a lining of acid-proof brick inside of the lead will serve as a protection to the latter against mechanical injury when the tank is cleaned. Since separation may require as much as two days' time, two tanks should be installed for an agitator treating once per day, and four tanks if two batches are treated in the agitator each day.

The separation is accomplished by agitation with air, followed by settling at temperatures of 150° to 200° F. The resulting layers separate by gravity and are, acid oil, weak acid and the so-called "acid cake" or coke. The first is an oil which after being neutralized may be reduced in fire stills to a petroleum pitch of high melting point. The coke as delivered from

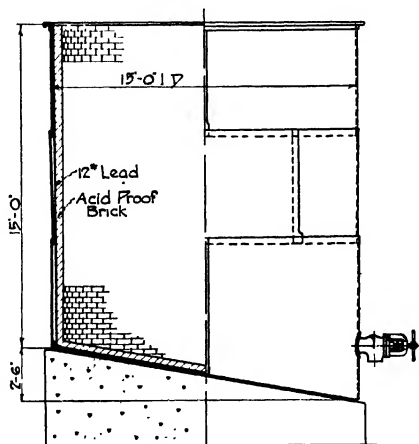


FIG. 225

Sludge acid separating tank.

the separators is rather of the nature of a heavy asphaltic tar. If it is washed with cold water, it becomes granular and coke-like in nature. Some refiners effect such washing on an inclined trough up which the mass is propelled by a spiral conveyor while water is sprayed over the length of the trough, draining to the sewers at the low end. The coked mass is delivered at the high end of the trough ready for disposal. If properly handled the resulting coke may be mixed with coal and burned. Another method of disposal is to flux the so-called coke with lighter oils, and then neutralize and use the resulting compound for local fuel about the refinery. If this method is followed, care must be exercised in the preparation of such fuel or the results will

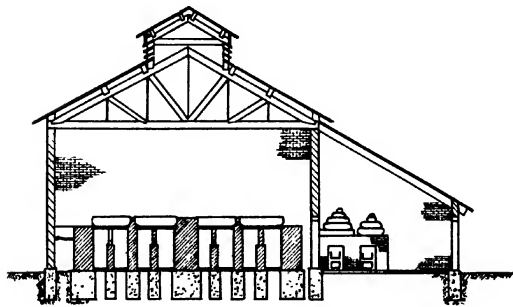
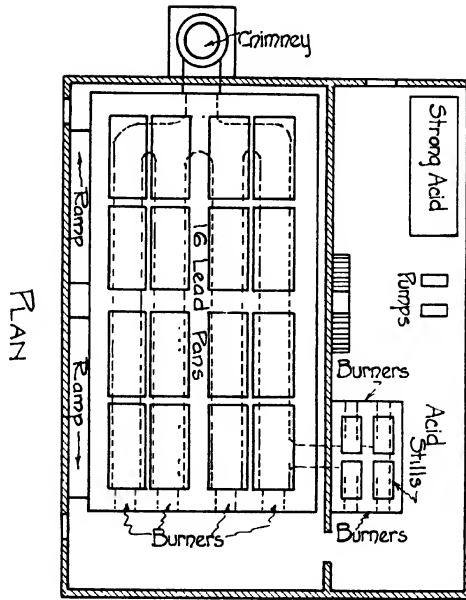


be discouraging, on account of corrosion of the oil burning equipment.

The weak acid, as recovered from the separators, has a specific gravity of 1.29 to 1.32, corresponding with (approximately) 33° to 35° B. for liquids heavier than water. Such an acid contains only about 37 per cent. of concentrated sulphuric acid, the balance being water with some organic compounds left from the treatment of the oil. The new commercial acid used in the refinery is of 1.835 specific gravity (66° B.) and contains about 93 per cent. of pure sulphuric acid ( $\text{H}_2\text{SO}_4$ ). For further use the weak acid derived from separation must be concentrated approximately to the last named specifications.

It was formerly the custom to ship this separated acid to chemical manufacturers for restoration. The wear and tear on equipment for its transportation and the cost of shipping the contained water led many of the larger oil companies to install recovery plants as departments of their refineries. It is doubtful whether the methods in use in the past produced results which paid the cost of such plants. In many cases, the cost of concentration was so large that better returns were derived when the weak acid was sold for what it would bring to industries which could make use of it, such as (for instance) fertilizer factories. For plants so situated as to be unable to sell this objectionable material, the difficulty of its disposal was so great as to warrant the installation of some method of concentration.

Weak sulphuric acid (up to about 1.70 specific gravity or 60° B.) is very corrosive to iron but has little effect upon lead. Acid heavier than 1.70, especially at temperatures near its boiling point is, on the other hand, destructive to lead and less active upon iron. For this reason early American practice developed the use of lead pans for concentration up to 60° B. The pans are 12 to 14 inches in depth and eight or more are arranged in series over flues conveying the hot gases of combustion from a coal or oil fired furnace. An evaporating surface from the pans of 50 to 65 square feet per ton of 66° B. restored acid from 35° weak acid per 24 hours will prove satisfactory. The acid



SECTION

FIG. 226

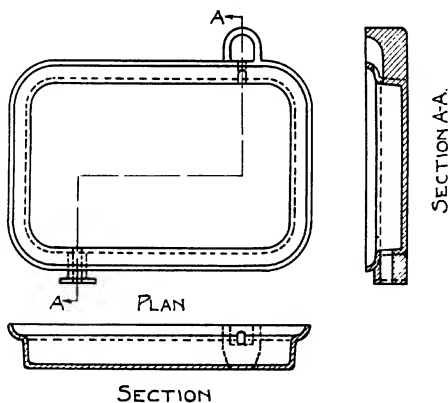
Pan house for restoring weak acid.

pans of refineries which have come under the author's observation conform quite closely with the above specifications.

Fig. 226 illustrates in general the construction of a pan bench. Chemical lead weighing 16 pounds to the square foot is recommended for the construction of the pans. The pans are so arranged that the acid enters the first pan at the rear of the bench, traveling back and forth toward the combustion end and thus gradually encountering the hotter flue gases. Every pan should be accessible for skimming, as the process is one of evaporation of the water, and any scum forming on the surface retards the action. The building should be so designed as to afford a natural circulation of air. This not only helps to abate the nuisance from fumes within the building but also assists in evaporation. In some localities, the operation of pan houses has been adjudged a public nuisance and efforts have had to be made to abate the fumes. Lead lined hoods over the pans, connected with ducts leading to an exhaust fan discharging into a high chimney, help to a large extent. Discharging at the high elevation of the chimney top, the fumes are carried great distances before settling and by that time are so diluted as to be unobjectionable. Some efforts have been made to recover the acid content of the fumes from the pans; but this acid content is very small, the evaporated portion being mostly water, so that it is doubtful whether commercial results warrant the effort.

The pans, as noted above, will reduce the acid to about 60° B., from which gravity it must be further concentrated to 66° B. In the early days, this was done in glass bottles, bedded in sand and placed over combustion chambers. Each bottle was filled, evaporated down to 66° B. and drawn off; a complicated operation, requiring much care and supervision. The breakage, fuel and general expense was naturally high. Platinum stills have been tried but (due to their excessive cost) abandoned in favor of cast iron stills. Stills of close-grained high quality foundry iron will last from 30 to 60 days in such service. Fig. 227 is a typical acid still, which resembles a pan rather than the conventional still. Lead covers or domes are placed over the stills.

These domes have lead troughs or flanges burned to their exterior, over which cooling water is passed. The fumes leaving the domes are condensed, since the acid content is now sufficient to return a condensate worth saving and also because of the obnoxious character of the vapors. Two or more strong acid stills are used in series, the acid flowing from the last one to storage. Separate ovens for firing are customary. In ordinary practice, the evaporating surface of the stills should approximate 4 square feet per ton of 66° B. acid recovered per day.



SECTION  
FIG. 227

Cast iron acid still.

A few notes on the general plant design follow. The use of concrete, especially around the pan and still benches, is not to be recommended. The acid is destructive to concrete and occasional spills are unavoidable. As before noted, the building should be extremely well ventilated. Large open areas near the ground line, with open roof monitors, are advisable. Concrete roofs on concrete columns have been used with success, provided the concrete is kept well covered with a protective coat of coal tar. Wooden roofs on wooden trusses are more usual. The best success is reported with long leaf yellow pine containing a high proportion of natural pitch. Wooden roofs, however, lead to a greater fire risk than do those of concrete.

The average so-called pan system, consisting of open lead pans and iron stills, has many objections. The fuel efficiency is low. From 1,250 to 1,500 pounds of coal per ton of 66° B. acid recovered are average figures. The labor costs are high and the maintenance costs excessive. The percentage of recovery of the acid is low; rarely over 85 per cent. and more often about 80 per cent. Above all, there is the obnoxious character of the whole process.

Mr. Lewis B. Skinner <sup>1</sup> has built pan-and-still sulphuric acid concentrators which vary somewhat from those ordinarily used. He uses large cast iron stills with cover connections to a small heat-exchange tower, so arranged that the fumes evolved from the hot strong acid are brought into contact, in the tower packing, with the cold acid being fed to the plant. By this means, much of the heat wasted in water-cooled condensers, together with the cost of repairs thereon, is saved. After being preheated in this manner, the feed acid passes to the pans.

For better economy than the pan system offers, Mr. Skinner recommends a tower plant. Four towers are used, the first for evaporating the weak acid to about 50° B., the second for concentrating to 66° B. and the remaining two for condensing the fumes formed in the second. Flue gases from combustion chambers attached to the two towers first mentioned pass counter-current to the acid, trickling down through the packing. The evaporation to 50° B. does not drive off acid fumes, so that no condensing tower is used here. The strong tower fumes pass through the two condensers in series and are cooled by recirculated distillate. While the flue gases are admitted at ordinary firebox temperatures, the use of tall towers with high arches does away with the greater part of the damage to packing and to brick-lined lead construction. The system affords the advantages of continuous running, economy in fuel (since the heat of the flue gases is all transferred to the acid), freedom from repairs and replacements and a much higher recovery of acid than is possible with a pan-and-still set. The evaporation to 50°

<sup>1</sup> Consulting Chemical Engineer of Denver, and former Vice-President and General Manager of The Western Chemical Mfg. Co.

B. separates oily matter which may be skimmed from the acid before decomposition begins.

The Chemical Construction Company, of Charlotte, N. C. and New York, have developed a patented system which also deviates from the old primitive methods. The basic principle involved is the blowing of hot air through the bath of acid to be restored. In accordance with the physical law of partial pressures, the boiling temperature of acid of a given gravity is reduced when air is introduced directly therein. The chart of Fig. 228 illustrates this fact graphically.

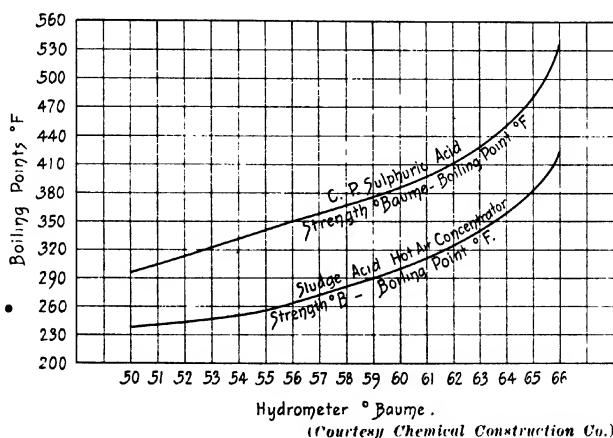


FIG. 228

Boiling points of sulphuric acid and effect of air blast in concentrator.

In practice, the acid is contained in a heavy rectangular lead pan lined with acid proof masonry. Over the pan is a brick arch through which the hot air pipes enter. At the rear is a tower of acid proof masonry about thirty feet high. This tower is loosely packed. The weak acid enters the top of the tower, scrubs the ascending vapors and absorbs heat. After passing through the tower, it falls into the pan through which the hot air is being blown, and is withdrawn at the end away from the tower.

Two such pieces of apparatus are used, as in Figs. 229 and 230, the first stage concentrating from 35° B. to 57° or 60°, and

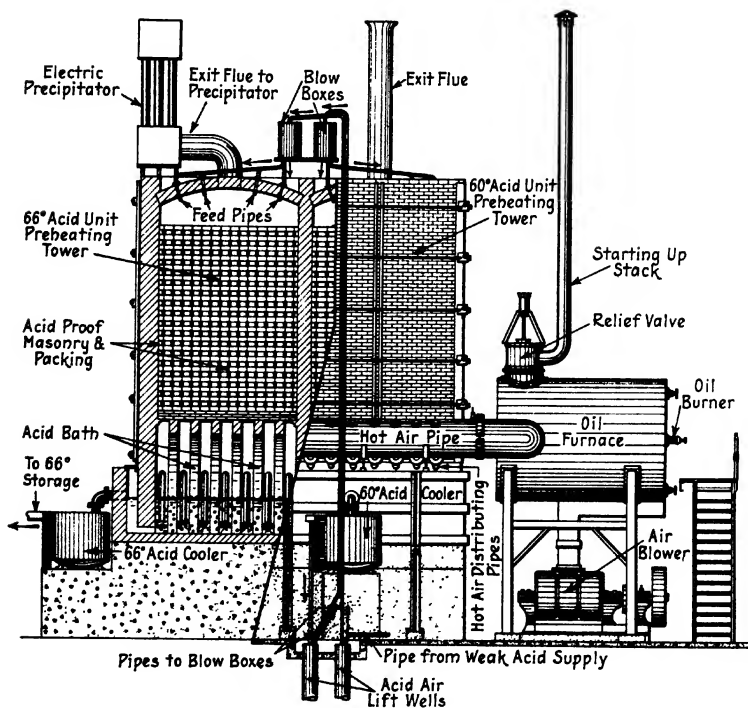


FIG. 229

System of acid recovery of the Chemical Construction Co.

the second stage completing the concentration to 66° B. The hot air is supplied by a blower discharging through a combustion chamber and is delivered under the surface of the acid at pressure merely sufficient to discharge up through the bath. The air temperature preferred is between 1,100° and 1,200° F. The gases leaving the first stage contain little or no acid and are claimed to be unobjectionable if discharged direct to the atmosphere. Those from the second stage contain some acid, and this is removed by additional scrubbing towers or by the Cottrell electrical precipitator.

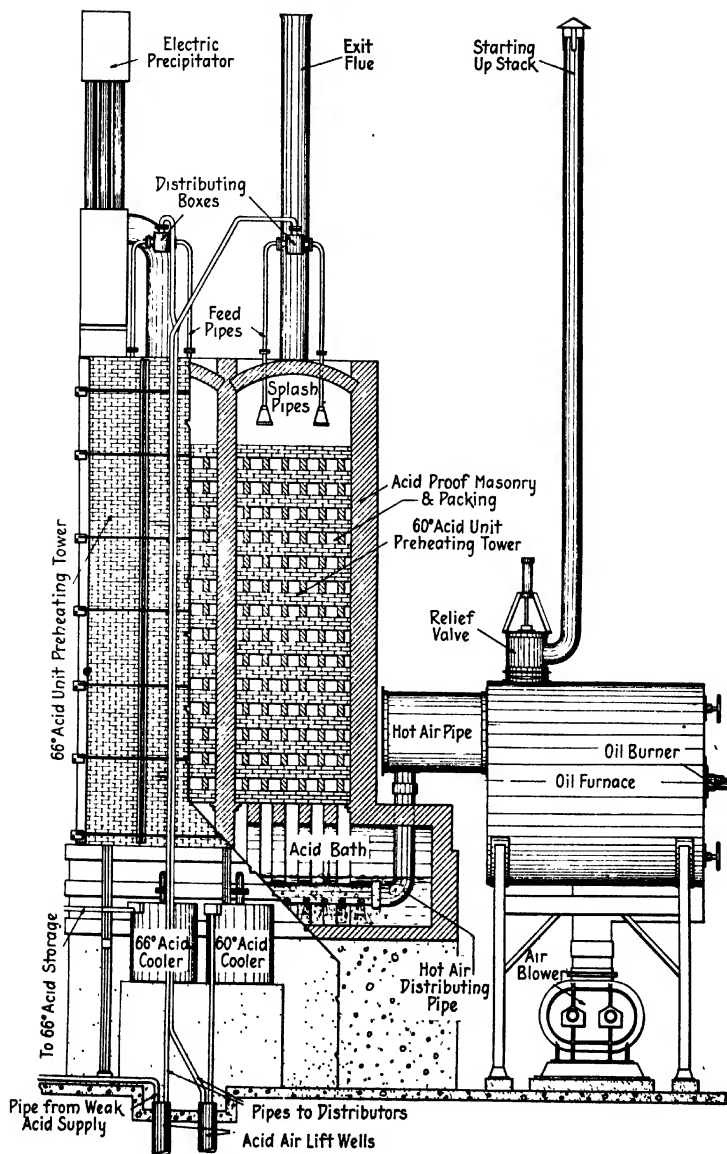


FIG. 280

Small acid recovery plant Chemical Construction Co.



In smaller units, the bath of acid is directly under the tower (Fig. 230). With this arrangement, plants are furnished of capacities from ten to twenty tons of restored acid per day. For larger plants (up to one hundred tons per day), the design of Fig. 229 is followed.



FIG. 231

Chemical Construction Company's system of restoring weak acid.

The advantages claimed for this system are as follows: Small area required in comparison with the pan bench and still; the ten ton plant occupying a floor space 46 by 36 feet and the 100 ton plant a space 100 by 66 feet, including all pumps, blower towers and intermediate storage tanks:

The fuel efficiency is good, operation showing less than 4 gallons of fuel used per ton of restored acid:

Labor requirements are reduced, it being stated that one man per shift can operate the system at any capacity up to 100 tons of restored acid per day:

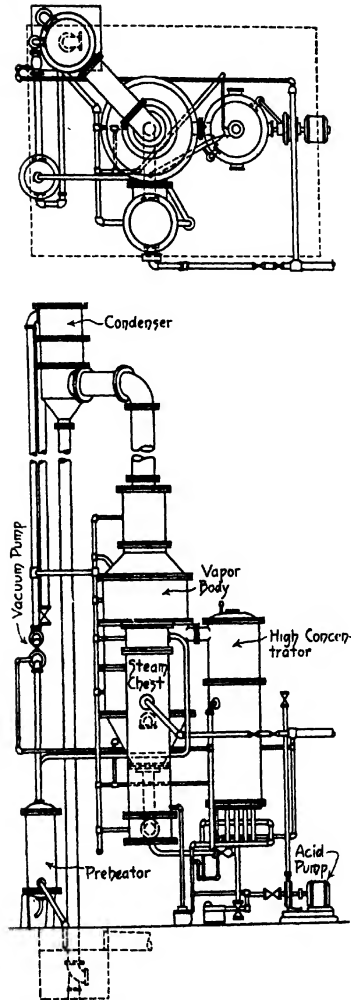


FIG. 232

Mantius system of weak acid restoration.

The percentage of recovery is high, being reported at from 90 to 95 per cent.

Freedom from repairs is also notable.

Another process recently developed is that of Simonson-Mantius (Fig. 232), in connection with which various patents have been granted or are pending. This process concentrates 30° to 35° B. weak acid to 66° B. in a closed system under a high vacuum. The vacuum greatly reduces the temperature necessary for concentration and hence steam at 150 pounds pressure is suitable for the heating medium, up to a concentration of 65° B. If 66° B. acid is desired, final concentration may be effected by the use of hot oil instead of steam for the heating medium. It should be noted that the 65° B. acid can easily be raised to 66° B. by adding a small quantity of fuming acid, thus eliminating the secondary concentrator. The vacuum is maintained by means of a barometric type condenser and the direct contact with the water in the condenser serves to absorb the fumes.

Units of this system are built in capacities of from 10 to 50 tons of concentrated acid per 24 hours. The fuel consumption is reported at 1.25 barrels per ton of acid recovered. The floor space for a given capacity is unusually small; for example, a 20 ton unit occupies only about 260 square feet, overall dimensions.

Other advantages claimed are the elimination of fumes, high percentage of recovery and elimination of a large part of the labor.

## CHAPTER XXII

### GENERAL DEPARTMENTS

Shops—Water supply—Cooling towers—Disposal of waste—  
Sanitary standards—Laboratories—Arrangement of docks—  
Loading racks—Pump houses.

The shops of a large modern oil refinery are a veritable manufacturing establishment in themselves. Repairs to apparatus require a large outlay for mechanical equipment which with a few additions will make the plant independent of outside metal and wood working plants for all normal extension work. The smaller skimming plants running under 10,000 barrels a day do not, of course, need such extensive shops; but should be equipped with one or two lathes, a shaper, a drill press and a pipe threading machine. Fig. 233 is a suggested arrangement for a shop in such a small plant.

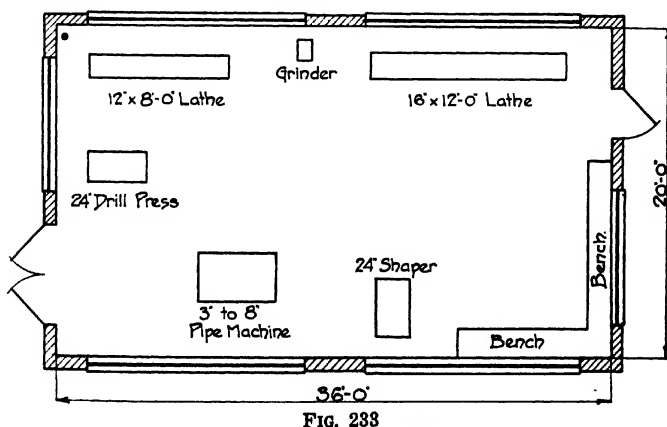


FIG. 233  
Floor plan of shop for small refinery.

Larger and more complete refineries will require, besides additional lathes and drills, more pipe machines, boiler shop

equipment and wood working machinery. Fig. 234 illustrates the general arrangement of the mechanical department recently designed for a complete refinery of 20,000 barrels estimated daily capacity. The arrangement was influenced in this case by the distance between the two main tracks to the north and south of the buildings, which could not be changed, because of topographical conditions. All buildings are served by the railroad switch, and all are grouped so that they are convenient one to the other while not disregarding the possibility of further extensions.

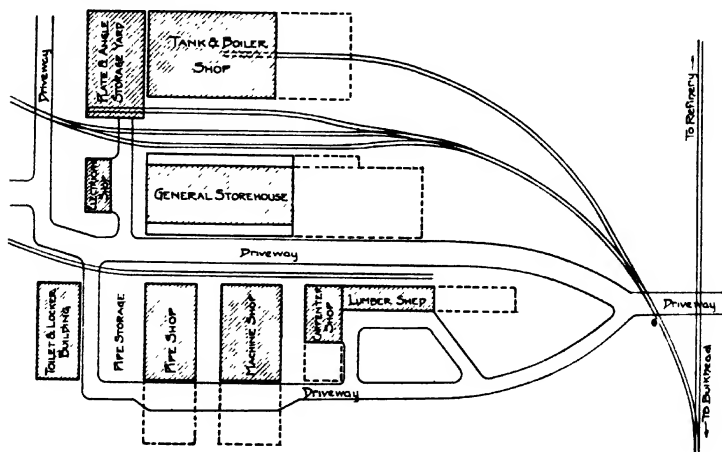


FIG. 234

Arrangement of shops for large refinery.

A description of the various shops with their equipment will illustrate the requirements.

Fig. 235 is a floor plan of the boiler shop. Primarily needed for still repairs, especially for those stills running to coke, a shop of this kind can turn out stills, condensers, tankage, filters and miscellaneous structural work for all normal expansion. The equipment embraces 2 combined vertical punches and shears, with capacity up to holes 1 inch in diameter through 1 inch plate, one rotary bevel shear of  $\frac{3}{4}$  inch plate capacity, one  $\frac{3}{4}$

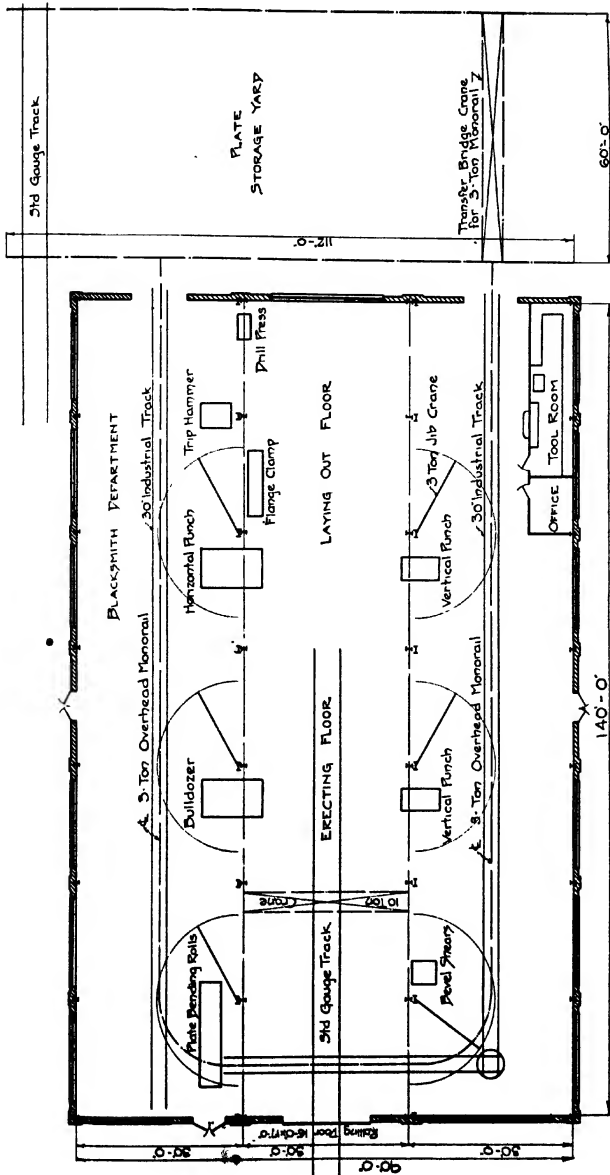


FIG. 235  
Floor plan of boiler shop.

inch plate rolls 12 feet between housings, one 22 inch cut-off saw, a bulldozer, a horizontal punch for flanges (capacity 1 inch through 1 inch), a 500 pound trip hammer and miscellaneous forges for blacksmith work. The work is fairly heavy, and efficient means of handling plates and shapes are necessary. For the shop illustrated, a 3-ton monorail track in U-shape is hung over the machines, the two open legs terminating at the 60 foot span crane runway at one end of the building. A transfer bridge travels on this runway, upon which the monorail may run and thus cover any part of the plate yard under the bridge. The bridge is controlled by the operator of the monorail.

The machines are placed in the order of their use, each served individually by 3-ton jib cranes. The plates brought in by monorail may be passed from jib crane to jib crane if desired. A 30 inch industrial track along the two outside bays and across one end is also valuable. A ten-ton crane in the center bay is necessary if small tanks and stills are to be erected inside.

Fig. 236 shows the machine shop. The equipment consists of 12 inch by 8 foot, 16 inch by 12 foot and 24 inch by 12 foot lathes and one 24 inch and 48 inch by 24 foot double spindle lathe, a 42 inch by 36 inch by 10 foot planer, a 25 inch shaper, a milling machine, a 5 foot radial drill, an 8 spindle multiple drill, a 25 inch drill press, a 2 inch bolt cutter and a keyseater. The tool room contains a small lathe and drill grinder. The larger machines are served by a three-ton hand-operated traveling crane. A 30 inch industrial track past the machines and leading to the pipe shop is useful.

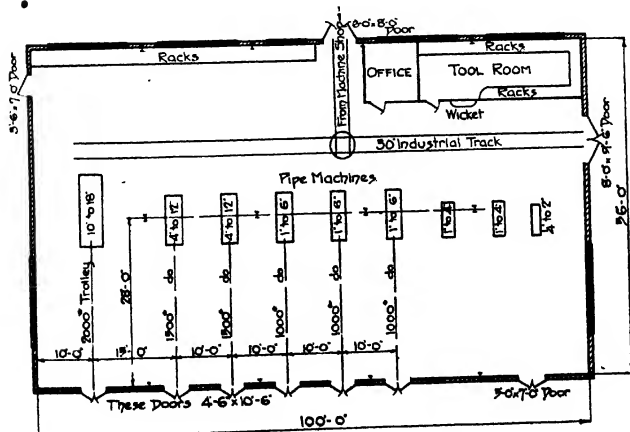
Considering the large amount of pipe work to be done in refinery, an efficient pipe shop is necessary. Fig. 237 illustrates the pipe shop of the group under discussion. Pipe cutting and threading machines of the following capacities are shown, one 10 inch to 18 inch, two 4 inch to 12 inch, three 1 inch to 6 inch, two 1 inch to 4 inch and one  $\frac{1}{4}$  inch to 2 inch. The points of particular interest are the doors placed opposite the larger machines with I-beam overhead trolley tracks for each machine,

A hand-drawn floor plan of a machine shop, measuring 100'-0" in width and 60'-0" in depth. The plan is divided into several functional areas:

- Top Section:** Contains a "Pench" (bench) at the top center. Below it, from left to right, are a "48 x 24' x 24'-0" Double Spindle Lathe", a "24 x 12'-0" Lathe", a "16 x 12'-0" Lathe", and a "12 x 6'-0" Lathe". A "25" Drill Press" is located on the far right. A "30" Industrial Track" runs horizontally across this section.
- Left Side:** Features a "6'-0" x 3'-0" Door" at the top and a "6'-0" x 8'-0" Door" at the bottom. A "Grinder" is positioned near the top left.
- Center:** Includes a "Turntable" in the upper middle. Below it, from left to right, are a "42 x 36 x 10'-0" Planer", a "25" Shaper", a "Milling Machine", and a "5" Radial Drill". A "Key Sealer" is located below the shaper. A vertical "10" Pipe Shop" runs through the center.
- Bottom Section:** Labeled "WELDING DEPT" in the lower left. It includes a "Bench" at the bottom center, a "Sensitive Drill", and a "3" Spindle Drill". A "2" Bolt Cutter" is located to the right of the pipe shop.
- Right Side:** Contains an "OFFICE" at the top right, a "Tool Room" below it, and a "Rocky" area at the bottom right. The Tool Room includes a "Table", "Prng Under", "Drill", "Grinder", and a "16" x 6" Lathe". A "Wicket" is located between the Tool Room and the Welding Dept.

Dimensions are marked along the edges: 100'-0" for the total width and 60'-0" for the total depth. Individual door sizes are noted as 6'-0" x 3'-0", 6'-0" x 8'-0", and 6'-0" x 8'-0".

**Floor plan of machine shop.**



Floor plan of pipe shop.



The other shops, not shown in detail, are the carpenter and the electrical. The former is equipped with rip saw, band saw, pony planer, wood lathe and jointer, and auxiliary equipment such as grindstone, saw filing machine and glue kettle. This shop can take care of all repairs, and in addition make doors, cut lumber for forms and do other miscellaneous work during construction periods. All patterns for castings may also be turned out. The work in the electrical shop is confined mostly to the bench variety.

First class standards for industrial construction apply. Brick walls, steel sash, and cement tile roofs are specified. Wood block floors for the boiler, machine and pipe shops are recommended. The machines are individually motor driven, the total connected load being as follows:

	Horsepower
Boiler shop .....	100
Machine shop .....	58
Pipe shop .....	45
Carpenter shop .....	27

In designing the power house, a load factor of 50 per cent. will suffice for the class of work the shops will do. The load is on only during the day shift under normal conditions.

The question of water supply is a vital one in oil refining. A pure fresh water supply is necessary for boilers and for treating departments. For condensers, the quality is not so important: even salt water may be used. Refineries often have three independent systems, as follows: fresh pure water from wells or other sources for agitators and boilers and sanitary use; general service supply for condensers, coolers and other similar uses; and a high pressure fire system. For the first two mentioned systems, a pressure in the yard of 25 pounds per square inch is satisfactory. The question of water for the fire system is discussed in detail in the chapter on "Fire Protection." In the writer's opinion, the fire system should be entirely independent of the other two. In case of fire, the pumps and lines should not have any other service dependent upon them. The other two systems may well be combined if the available supply of

fresh pure water is sufficient to take care of both requirements at all times.

There is an old saying in oil plants that "a refinery never has too much water." It often happens, however, that through carelessness, condensers are run unnecessarily cool, with consequent waste of water. An analysis of the water consumption of 8 plants of five different companies shows the water consumption in gallons per 24 hours per barrel of crude run to be:

TABLE 65. WATER CONSUMPTION

1. Complete lubricating refinery .....	540
2. Complete lubricating refinery .....	630
3. Skimming and cracking .....	910
4. Half skimming, half lubricating .....	250
5. Topping only 25 per cent. ....	210
6. Lubricating refinery .....	440
7. Complete refinery .....	800
8. Complete lubricating refinery .....	1,020

Numbers 3, 7 and 8 were handicapped by an unusually warm supply of water, 70° to 75° being reported in summer. Plant No. 4 cooled and recirculated most of the water, with consequent low consumption. For normal conditions, with average water temperatures over the year of from 50° to 60° F., the writer recommends 650 gallons per day for complete lubricating refineries and 300 gallons per day for skimming plants, for each barrel of crude oil put through the refinery.

For lubricating works, in cases where this water supply must be divided into two systems, allow 75 gallons of fresh pure water for boilers and treating, and 575 gallons of water suitable only for condensers, per barrel of crude oil charged per day. For skimming plants, 30 and 270 gallons respectively will suffice. Many plants may be said to lie in between the two types above, which represent the two extremes in water consumption. For instance, refineries running on such an oil as that from the Goose Creek field, while strictly lubricating plants, still do not require as many operations to finish their product and hence do not require the full quantity of 650 gallons proposed above. Judgment must therefore be used; and when there is any doubt

it should be considered that too much water is better than not enough.

In many localities, the question of water supply is serious. Particularly in the Mid-Continent field, water is often at a premium. In such cases, suitable cooling apparatus is an economic necessity. While with most problems of heat transfer, the temperature difference governs the rate, in the case of spray ponds and cooling towers this is true only if the atmosphere is fully saturated. In cooling apparatus of the above type, the heat loss is made up of both direct transfer and latent heat absorbed from the water due to evaporation.

Tests of cooling ponds with Schütte & Koerting spray nozzles, conducted at the Massachusetts Institute of Technology, have led to the following conclusions.<sup>1</sup>

1. The temperature of the water after spraying is more dependent upon the temperature and humidity of the atmosphere and the fineness of the spray than upon the initial temperature of the water.

2. At high humidity, 80 to 90 per cent., the temperature of the water may be lowered to within 12° or 13° of the temperature of the air, with a total drop in temperature of 35° to 40°.

3. At low humidity, 20 to 30 per cent., the temperature of the water after spraying may be as much as 8° below the temperature of the air and the total drop in temperature may be 40° to 45°.

4. The loss of water by evaporation is approximately 0.15 pounds per degree of lowering of temperature per 100 pounds of water discharged, or the gross loss is about 6 per cent., for 40° lowering of temperature. In no case was the loss found to exceed 7 per cent.

The total exposed surface of the spray jet is such that less air per pound of water is met than in the cooling tower. Oftentimes a portion or even all of the water is sprayed over a second pond to increase the surface. In cases of high wind velocity, the

<sup>1</sup> Harding and Willard, *The Mechanical Equipment of Buildings*, pp. 454 and 455.

loss of water is often excessive. For these reasons many engineers prefer the cooling tower.

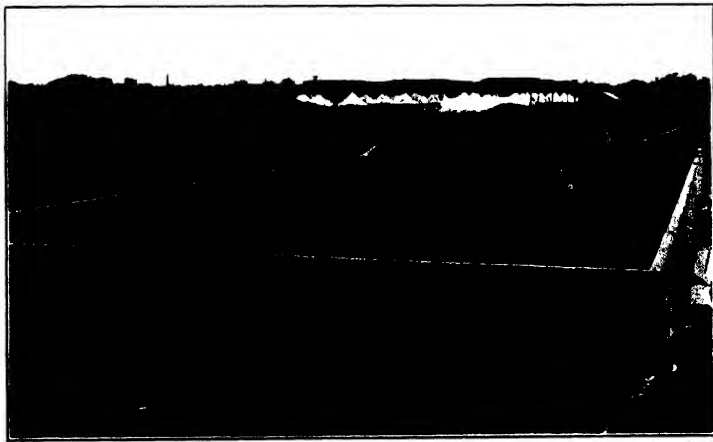
Results obtained in towers are influenced chiefly by the humidity. The surfaces exposed, however, exceed those of the spray pond. Without the use of prohibitively large towers, final water temperatures within  $5^{\circ}$  to  $10^{\circ}$  of the wet bulb temperature can be obtained. A water temperature drop as great as  $100^{\circ}$  can be realized and results are often recorded of final water temperatures  $20^{\circ}$  to  $25^{\circ}$  below the dry bulb air temperatures.

In the above, the terms *wet bulb* and *humidity* have been used. Without going too deeply into the matter, the wet bulb temperature may be described as being roughly equal to (actually a little below) the temperature at which evaporation takes place. It may be recorded by a thermometer, around the bulb of which is placed a moist cloth. The relative humidity is the ratio of the weight of moisture actually mixed with one pound of dry air at any stated temperature, divided by the weight of moisture contained per pound of dry air when such air is *saturated* with vapor at the same temperature. Charts and tables are available from which the relative humidity may be determined from the wet bulb and dry bulb temperature readings.

The selection of cooling apparatus is an economic problem. Balanced against the cost of a pond or tower with its circulating pumps and lines, with their operating costs, is the reduced cost of equipment, power and labor for pumping only 2 to 10 per cent. of the amount of water that would be needed if cooling towers were not used.

Waste water disposal is accomplished through an elaborate sewerage system. For ordinary purposes, double strength sewer tile is satisfactory for the smaller sizes and reinforced concrete pipe for larger lines. Where extremes of temperature are likely to occur, sewer tile will check and crack; so that for this condition, cast iron bell and spigot pipe is better. The condenser run-off can be handled in tile, however, since the number of stills running usually keeps the temperature fairly uniform. If only one condenser is on a line, trouble may be experienced. It will

pay to run sewers past all yard tanks and to place a catch basin at each water drawoff, thus recovering spills of oil. The precautions described in the chapter on "Fire Protection" should be followed when designing the sewer system. With adequate sewer sizes to accommodate multiple hose streams at any point, the question of storm water need, in the majority of cases, receive no further attention.



*(Courtesy Turner Construction Co.)*

FIG. 238

Reinforced concrete separator or "trap" for refinery waste.

The water reaching the sewers will also carry oil in all its various stages of manufacture. This oil content will come from leaking cooler and condenser fittings and from occasional discharges through safety valves but more largely from drawing off water bottoms from tanks and from accidental spills. One-half of one per cent. to one per cent. of the crude throughput is often lost in this way. Its recovery is important, not only from a financial standpoint, but because if allowed to flow into streams or other bodies of water, contamination would follow.

A separator or trap to catch this oil is part of all modern plants. The principle is the reverse of the settling basin, in that the material it is desired to retain is lighter than water

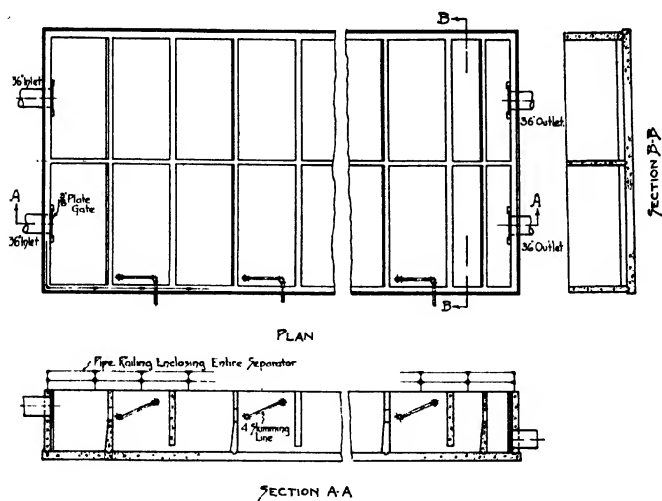
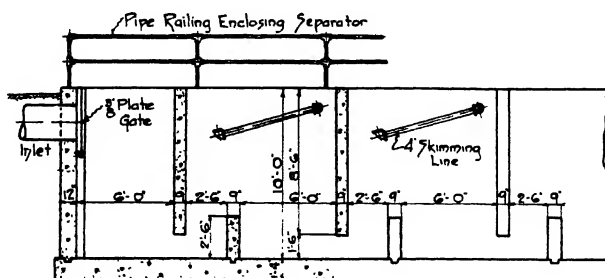


FIG. 239

Concrete oil separator.

and hence accumulates on the surface. A rectangular tank with baffles is the usual construction. Figs. 238 and 239 illustrate concrete separators of this type. Some refiners claim that for heavy oils whose gravity approaches that of water the settling or descending velocity between the "over" or retarding baffle and the "under" or skimming baffle is sufficient to carry the oil under the latter with consequent trouble. They recommend the construction shown in Fig. 240 which deflects the current slightly upward, just before the skimming baffles are reached. As the normal run off will closely approximate the amount of water pumped, a design based on that quantity will prove satisfactory. For efficient separation, the velocity should not exceed 1.5 feet per minute and the length of time for passing

through the separator should not be less than 80 to 90 minutes. Given the amount of water pumped and the depth of flow in the separator, the dimensions may be quickly determined. A length-wise partition through the center is advisable, since it not only decreases the cost by reducing bottom and baffle spans, but also allows one side to be shut off for cleaning or repairs without putting the whole device out of service. The end baffle may be in



LONGITUDINAL SECTION

FIG. 240

Concrete oil separator showing "low" type of baffles.

the form of a weir, whereby measurements may be made of the run off quantity. These will give a rough check on the pumping records.

Sanitary conveniences are prescribed by law in most states. Modern industrial trend is towards careful attention to the health and welfare of the employee. Locker, lunch room and sanitary conveniences are now considered a question of importance. The standards of one prominent company call for better facilities in this respect than any of the state laws examined by the author, and if followed will be ample for any legal requirements. These standards are reproduced herewith.

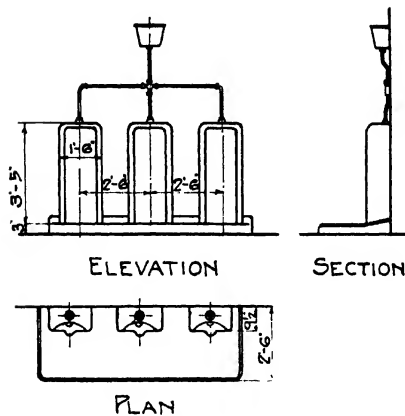


FIG. 241

One flush tank to supply not more than three urinals. Each urinal to have an individual non-syphoning lead clean-out trap, with threaded brass cover, set flush with raised floor. Traps to be located between stalls and far enough back of standing platform to avoid their forming an obstacle.

For 1 to 15 employees	{ 1 urinal per 7 employees on day work 1 urinal per 7 employees on shift work i.e. 1 urinal per 21 employees constituting 3 shifts
For 15 to 40 employees	{ 1 urinal per 15 employees on day work 1 urinal per 15 employees on shift work i.e. 1 urinal per 45 employees constituting 3 shifts
For 40 to 100 employees	{ 1 urinal per 25 employees on day work 1 urinal per 25 employees on shift work i.e. 1 urinal per 75 employees constituting 3 shifts
For 100 to 500 employees	{ 1 urinal per 35 employees on day work 1 urinal per 35 employees on shift work i.e. 1 urinal per 105 employees constituting 3 shifts
For 500 to 1000 employees	{ 1 urinal per 50 employees on day work 1 urinal per 50 employees on shift work i.e. 1 urinal per 150 employees constituting 3 shifts
For 1000 to 1500 employees	{ 1 urinal per 75 employees on day work 1 urinal per 75 employees on shift work i.e. 1 urinal per 225 employees constituting 3 shifts



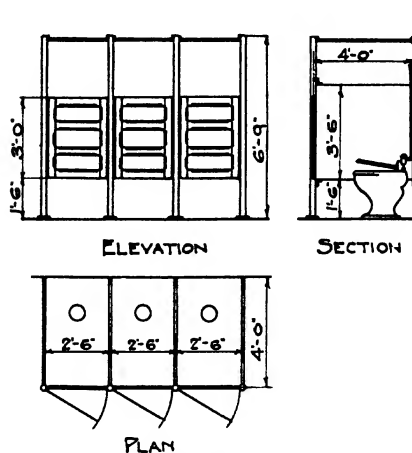


FIG. 242

Water closets:—White vitreous china silent action syphon jet closet.

Stalls:—Partitions to be C.I. painted for toilet rooms located under condenser boxes or where exposed to gases. Other places sheet metal painted or  $\frac{1}{8}$  inch slate.

For 1 to 15 employees	{ 1 W.C. per 5 employees on day work { 1 W.C. per 5 employees on shift work i.e. { 1 W.C. per 15 employees constituting 3 shifts
For 15 to 40 employees	{ 1 W.C. per 10 employees on day work { 1 W.C. per 10 employees on shift work i.e. { 1 W.C. per 30 employees constituting 3 shifts
For 40 to 100 employees	{ 1 W.C. per 20 employees on day work { 1 W.C. per 20 employees on shift work i.e. { 1 W.C. per 60 employees constituting 3 shifts
For 100 to 500 employees	{ 1 W.C. per 30 employees on day work { 1 W.C. per 30 employees on shift work i.e. { 1 W.C. per 90 employees constituting 3 shifts
For 500 to 1000 employees	{ 1 W.C. per 35 employees on day work { 1 W.C. per 35 employees on shift work i.e. { 1 W.C. per 105 employees constituting 3 shifts
For 1000 to 5000 employees	{ 1 W.C. per 40 employees on day work { 1 W.C. per 40 employees on shift work i.e. { 1 W.C. per 120 employees constituting 3 shifts

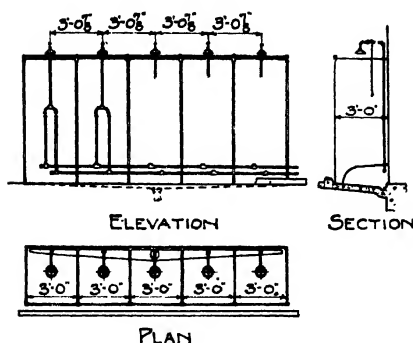


FIG. 243

Showers:—Shower heads 5 inches in diameter. Stalls to be made of slate not less than  $\frac{7}{8}$  inch thick. Stalls braced in front with  $1\frac{1}{4}$  inch nickel plated brass tubing. Floor to be made of one part cement and two parts sand finish troweled smooth and waterproofed if necessary. Drains for each five stalls. Furnish wood floor mat for each shower compartment.

For 1 to 15 employees	<ul style="list-style-type: none"> <li>1 shower per 15 employees on day work</li> <li>1 shower per 5 employees on shift work i.e.</li> <li>1 shower per 15 employees constituting 3 shifts</li> </ul>
For 15 to 40 employees	<ul style="list-style-type: none"> <li>1 shower per 15 employees on day work</li> <li>1 shower per 7 employees on shift work i.e.</li> <li>1 shower per 21 employees constituting 3 shifts</li> </ul>
For 40 to 100 employees	<ul style="list-style-type: none"> <li>1 shower per 20 employees on day work</li> <li>1 shower per 10 employees on shift work i.e.</li> <li>1 shower per 30 employees constituting 3 shifts</li> </ul>
For 100 to 500 employees	<ul style="list-style-type: none"> <li>1 shower per 30 employees on day work</li> <li>1 shower per 20 employees on shift work i.e.</li> <li>1 shower per 60 employees constituting 3 shifts</li> </ul>
For 500 to 1000 employees	<ul style="list-style-type: none"> <li>1 shower per 40 employees on day work</li> <li>1 shower per 25 employees on shift work i.e.</li> <li>1 shower per 75 employees constituting 3 shifts</li> </ul>
For 1000 to 5000 employees	<ul style="list-style-type: none"> <li>1 shower per 50 employees on day work</li> <li>1 shower per 30 employees on shift work i.e.</li> <li>1 shower per 90 employees constituting 3 shifts</li> </ul>

Wash sinks:—Sinks 30 inches x 6 feet enameled inside; rim of sink to be 31 inches from floor. For wall mountings use 13½ inches x 6 feet. Warm water is to be supplied to wash stand faucets by means of Power Regulator Co.'s or equal thermostatic steam and water mixer to be installed in the following proportion: 25 G.P.M. capacity for 18 faucets or less  
40 G.P.M. capacity mixers for 36 faucets or less

For 1 to 15 employees	{ 1 faucet per 2 employees on day work { 1 faucet per 2 employees on shift work i.e. { 1 faucet per 6 employees constituting 3 shifts
For 15 to 40 employees	{ 1 faucet per 3 employees on day work { 1 faucet per 3 employees on shift work i.e. { 1 faucet per 9 employees constituting 3 shifts
For 40 to 100 employees	{ 1 faucet per 5 employees on day work { 1 faucet per 5 employees on shift work i.e. { 1 faucet per 15 employees constituting 3 shifts
For 100 to 500 employees	{ 1 faucet per 8 employees on day work { 1 faucet per 8 employees on shift work i.e. { 1 faucet per 24 employees constituting 3 shifts
For 500 to 1000 employees	{ 1 faucet per 10 employees on day work { 1 faucet per 10 employees on shift work i.e. { 1 faucet per 30 employees constituting 3 shifts
For 1000 to 5000 employees	{ 1 faucet per 15 employees on day work { 1 faucet per 15 employees on shift work i.e. { 1 faucet per 30 employees constituting 3 shifts

Drainage from sanitary plumbing, on account of the great dilution, may be allowed to pass through the refinery trap or separator without fear of nuisance. The only precaution necessary is to run separate sanitary sewers to a point beyond the last fire trap on the larger sewers.

Laboratories vary all the way from the elaborate combined office, workshop and research buildings for a whole group of refineries, to the little testing room designed for the small plant making only two or three products. For the average small plant, one room large enough to accommodate the testing work will suffice. For larger complete refineries, division of the work usually falls under three headings, testing or control, research and experimental. Separate rooms should be provided for each. The testing room should be ample in size and be accessible directly from the plant. The research room should be inaccessible

from the outside. The most interesting portion is the experimental department. This consists of a miniature refinery, usually on a one-barrel scale, with fire and steam stills, agitators, filters and all equipment necessary to reproduce any refining operation. Here new crude oils may be run to determine their yields of various products, and new combinations of processes tried in the effort to improve practice in the plant. If in the hands of competent men, the results of the experimental laboratory will permit the forecast of commercial results in the refinery proper.

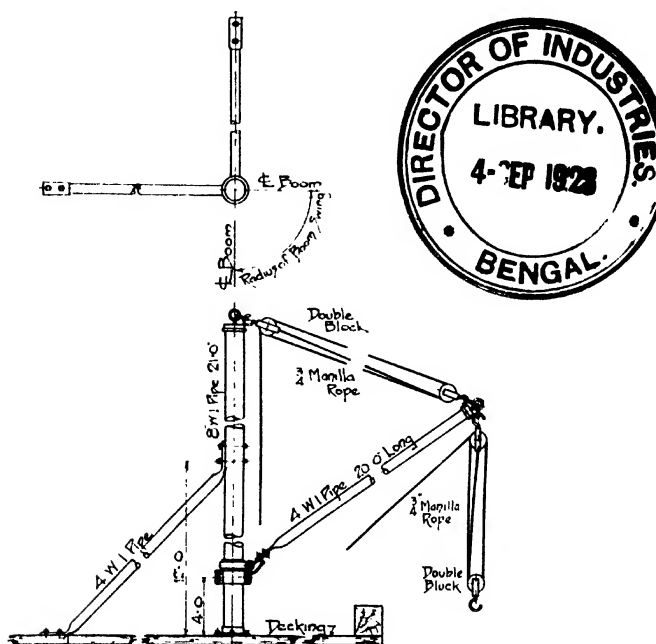


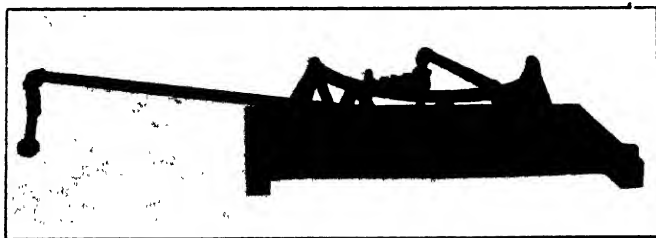
FIG. 244

Gaff for steamer discharge hose.

Refineries on the sea coast or on navigable streams rely largely on tank steamers for oil movement. Docks are therefore an important consideration. It is beyond the purpose of

this volume to attempt to cover the question of design of harbor structures, but there are a few details of refinery docks worthy of consideration. If bulk goods only are handled, there is no cause for building any obstructions along the water front. The oil lines should be brought along the face of the dock, the nearest being 6 to 8 feet from the edge. Outlets every 100 feet will accommodate the average ship very nicely. Heavy rubber cargo hose is used to connect the lines to the vessel. This comes in 4, 6, 8- and 10 inch sizes, in lengths usually of 15 feet, with companion flanges on each end. The hose serves to give the necessary flexible connection between shore and ship. A 10 inch hose is extremely stiff and unwieldy and two 8 inch are recommended rather than one 10 inch, for this reason. To handle the hose gaffs with tackle are necessary at each pipe outlet. Fig. 244 shows a satisfactory arrangement.

The use of hose is awkward, and to overcome the difficulties, a universal connection, Fig. 245, made entirely of pipe and fittings, is recommended by one prominent company. This is reported to give entire satisfaction.



*(Courtesy Freeport and Mexican Fuel Oil Corp.)*

FIG. 245

Flexible swing for dock to steamer connections.

The line sizes to the dock should be ample. When the great expense of holding a steamer at the dock even a few hours longer than necessary is realized, the small extra cost for adequate pumps and lines seems well warranted. Chapter XVIII gives data on tank ships.

In addition to the oil lines, the following pipes should also be laid to the dock; a steam line, ample to run the ship's pumps (as the fires aboard are usually drawn when pumping ashore); a fresh water line to replenish the water tanks aboard; and an air line to run pneumatic tools for minor repairs on the ship. Since loading goes on day and night, ample lighting facilities are necessary. Flood lights, so deflected as to illuminate the vessel's sides and the oil lines, are very effective.

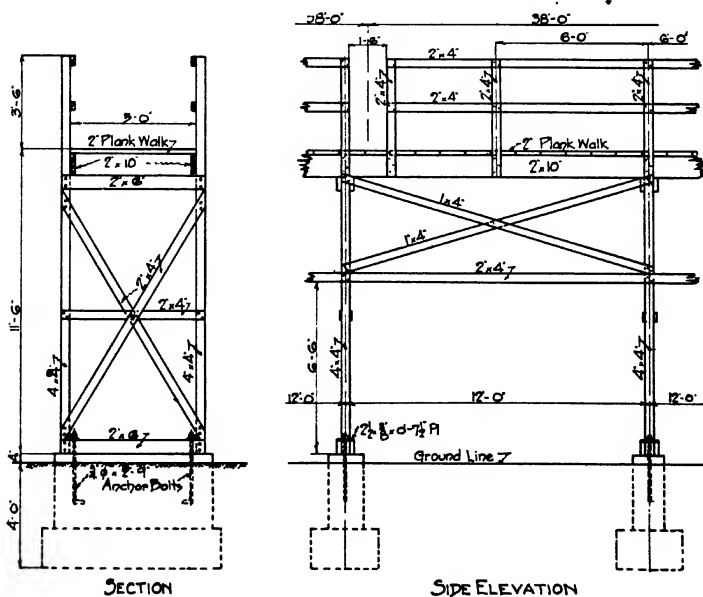


FIG. 246

Loading rack of frame construction.

Loading racks for tank cars vary from the small wooden platform at each pipe riser to the elaborate concrete structure accommodating a whole train of tank cars at one time. Generally a continuous runway about 14 feet above the rail is preferred. It may be of wood, steel or concrete. Typical designs of the three types are shown by Figs. 246, 247 and 248. Racks



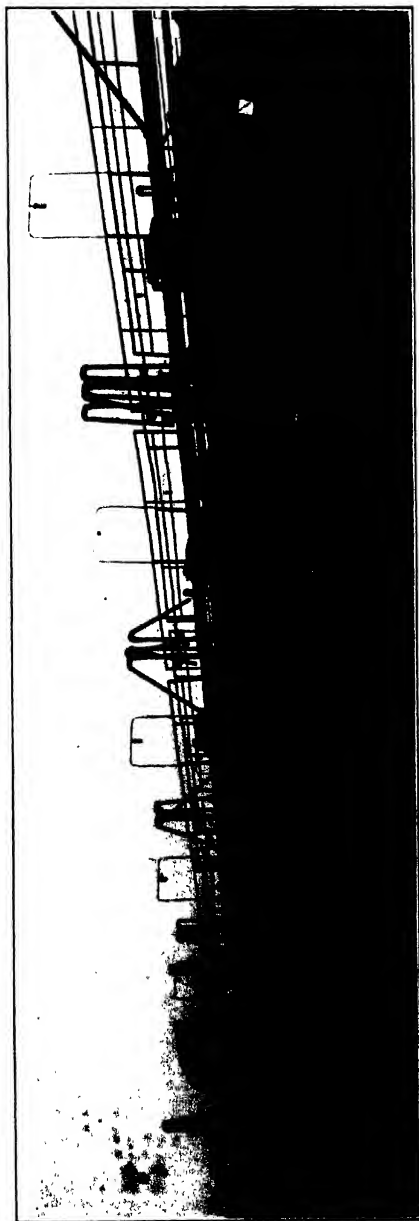


FIG. 249  
Refinery loading rack of steel construction.



tically always acceptable, so that the two track centers, with the rack between, are 22 feet apart. In addition to the oil filling lines, both steam and air are often required. A sewer paralleling the rack, with frequent catch basins for service in case of

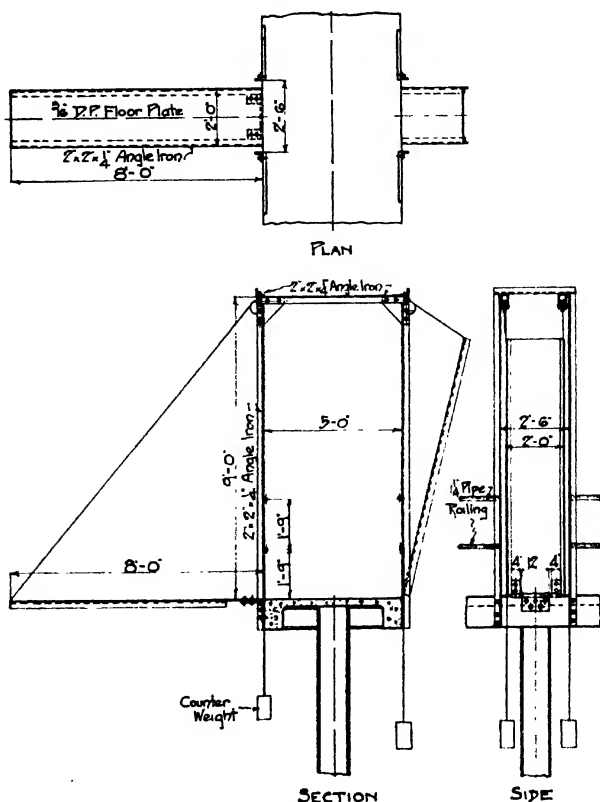


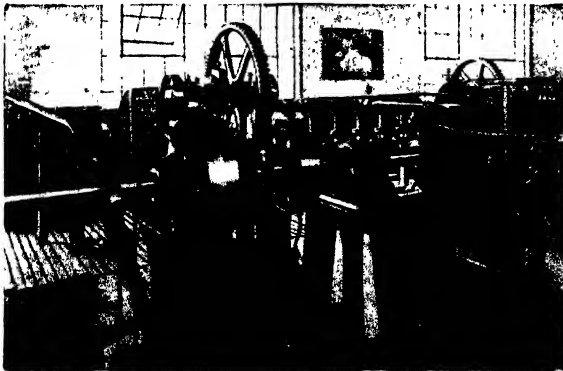
FIG. 250

Weighted gangway for loading racks.

spills, is also valuable. In locating or laying out tracks for loading racks the bulletins of the Bureau of Explosives of the Interstate Commerce Commission should be consulted, and also the standards of the railroad which will serve the plant.

When spacing the outlet or filling risers for a loading rack, the largest cars likely to be served should be considered. At present 38 foot centers of risers is satisfactory but, looking to the future, many refiners space their outlets 40 feet. To enable rackmen to go out to the tops of the cars for gauge and temperature readings, openings should be provided in the side rails of the rack. Planks to shove out to the cars have been used to a great extent, but are not used without some danger to the man, especially in winter weather. A wider gangway of steel, so weighted that it will automatically stand vertical and close the gap in the side railing, is suggested by Fig. 250.

Pump houses, while not strictly constituting special departments, may, nevertheless be well considered in this chapter. They may range from the central pump house of a large establishment to small installations of two or three isolated pumps. Great varieties of preference are exhibited by different refiners as to type of equipment. Direct acting duplex steam pumps are



(Courtesy Morse Chain Co.)

FIG. 251

Triplex pumps with clutches and silent chain drive.

probably the most popular. In recent years, effort to obtain higher efficiencies has led many refiners to install various types of power-driven equipment, but the demand for exhaust steam in

process work is always present and it is interesting to note that some of the most recently built plants are equipped with steam pumps. They have the advantage of simplicity, low first cost, operators' familiarity and flexibility; and if the exhaust can be used, they offer very fair overall operating costs. Centrifugal pumps are often used for gasolines, naphthas and burning oils, but are ill adapted to the more viscous products. For the light oils, motor drives should be avoided as hazardous, especially with D.C. current. Steam turbines are satisfactory but in small sizes are not particularly economical. It should be noted that centrifugal pumps should be set to provide gravity flow to the pump, to avoid the troublesome necessity of priming the suction line.

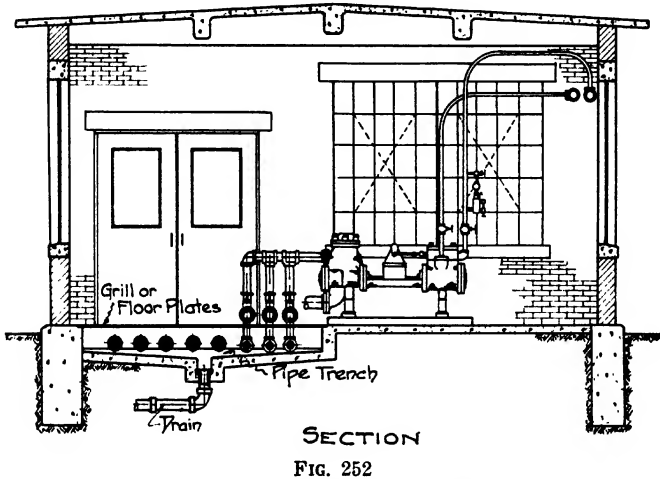
Triplex power pumps are often used for all classes of petroleum products. Without pulleys or gear changes these pumps operate at constant speed, a characteristic not usually satisfactory.

Triplex pumps operated from a line shaft (Fig. 251) driven by a steam engine form a popular arrangement. While expensive to install, the system is reliable and has fairly high economy under a fair load. The objections are, the constant pump speed and the poor economy which results if most of the pumps are shut down.

Rotary pumps also have their advocates and successful installations, particularly for viscous oils and waxes, are reported.

Motor drives for oil pumping are of doubtful advisability. Safety precludes their use for light oils. The heavier oils present a peculiar problem for the electric drive. The viscosity of such oils is a property that varies with temperature, hence a variable pressure head and motor load is bound to occur. Again, the pump may at one time be pumping to a far distant tank and shortly thereafter to one close at hand, resulting in further uncertainty of load. The motor size must be selected so as to take care of the worst conditions and as a result the motor is usually operating at an output far below its rating. Particularly in the case of alternating current, these conditions offset the possible economies. For far-distant installations of a very

few pumps, the electrical method of driving is justified when the cost of steam mains as against that of electric current distribution is considered; but in other cases the electrical system should be carefully weighed in comparison with other methods of delivering the power.



Section of small pump house.

General arrangements of pump houses vary but little. Fig. 252, showing the section of a pumping station using steam pumps, is typical. Many southern installations economize in building costs by placing all manifolds out of doors.

## CHAPTER XXIII

### FIRE PROTECTION

Building standards—Exposures—Fire pumps and mains—  
Use of steam—The “Foamite” system—Emergency sewers  
—Fire-banks and fire-walls.

The best fire protection is “fire prevention” and “fire prevention” can be practiced at no time to better advantage than when designing the plant.

For purposes of comparison, the following classification of buildings will be useful:

*Class A: Fireproof*

Pump houses  
Filter plants  
Wax plants  
Laboratories  
Filling houses

*Class B: Fire-resistant from exterior*

Power houses  
Shops  
Still sheds  
Barrel factories  
Can factories  
Warehouses

*Class C: Non-fireproof*

Temporary buildings  
Buildings not exposed to or offering risk from or  
to other structures.

**Class A:** Buildings should be reinforced concrete frame with tile or brick curtain walls. Steel sash with wire glass and metal covered doors should be used. Buildings with steel frames and trusses are acceptable if all steel work is properly protected. It must be realized that exposed roof trusses, for instance, will

fail quickly if subjected to a hot oil fire underneath. When steel trusses are used, cement tile or thin concrete slab roofs are recommended.

**Class B:** These buildings include those in which the risk from inside fires are slight, but which are desired to be practically fireproof from the outside exposure. Exposed steel work is allowable under these conditions, and the choice is a matter of cost only, between reinforced concrete, and brick-and-steel. Steel sash, metal covered doors and fireproof roof coverings are essential.

**Class C:** Covers frame buildings or those with brick walls and wood roofs. Doors and windows are of ordinary wood type.

After the selection of the type of building, the question of exposure is important. The underwriters charge the following increments as percentages of the unexposed rates for exposure to tanks containing oil and to stills:

TABLE 66. EXPOSURE RISK. BUILDINGS FROM TANKS

Exposure to Capacity (Bbl.) of Tank (or Group)		Tanks			Stills
		Up to 1,000	1,001 to 5,000	Over 5,000	
Distance	1. Less than 25 feet.....	15	15	15	10
	2. Less than 50 feet.....	5	10	15	5
	3. Less than 100 feet....	—	5	10	—
	4. Less than 200 feet....	—	—	5	—

Judgment should be used in this connection, since close proximity of the building to the exposure may, from an operating cost standpoint, more than balance the increased premium.

Tanks for refineries are often classed as "groups" by the underwriters, where such tanks are not separated by at least 25 feet of clear space. If any tank exceeds 5,000 barrels' capacity, all tanks within 50 feet of such tank are included in the group.

Tank exposure *from* buildings is rated by the underwriters at the following charges as a percentage of the risk when unexposed:

TABLE 67. EXPOSURE RISK. TANKS FROM BUILDINGS

## GRADE OF EXPOSURE

Small	Normal	Large	Charge
Up to 1,000 bbl.	1,001 to 5,000 bbl.	Over 5,000 bbl.	
Within 10 feet	Within 20 feet	Within 40 feet	15
10 ft. and under 15 ft.	20 ft. and under 30 ft.	40 ft. and under 60 ft.	10
15 ft. and under 25 ft.	30 ft. and under 50 ft.	60 ft. and under 100 ft.	5

Exposure of one refinery tank or group from other tanks or stills is rated as follows in percentage of the risk when unexposed:

TABLE 68. EXPOSURE RISK. TANKS FROM TANKS

	Small	Normal	Large	Stills
Less than 25 ft.....	Group	Group	—	10
Less than 50 ft.....	5	10	Group	5
Less than 100 ft.....	—	5	10	—
Less than 200 ft.....	—	—	5	—

Farm tanks (over 10,000 barrels containing crude oil) carry extra premiums when so spaced that the clear distances between them are as follows:

	Per Cent
Within 100 feet .....	15
Within 280 feet .....	10
Within 380 feet .....	5

Crude tanks located on refinery premises or provided with steam and/or foam systems are classed as refinery tankage rather than "farm."

High pressure water mains for fire fighting are important. Water directly on an oil fire often does more damage than good, but its assistance is invaluable in keeping adjacent tanks and buildings cool, as well as for preserving the lower rings of the burning shell. The underwriters ask for double hydrants within 300 feet of a risk, with water supply sufficient to maintain 30 pounds pressure while allowing a full flow through a 2½ inch outlet. The writer would further advocate hydrants so spaced as to allow six streams to be concentrated at any point, with no hose line to exceed 400 feet in length. Standard rubber-lined

fire hose of 2½ inch size, with nozzles and wrenches, should be placed on reels or carriages at strategic points and reserved strictly for fire use. Hose and hydrant threads should agree with those of the local fire department, if there is any. It is unnecessary to dwell on the necessity for inspection of this equipment at least every month.



FIG. 253

Burning oil tank.

Fire pumps should have ample capacity for any emergency. As a guide, the following capacities are suggested for complete refineries dependent upon their own resources for water. Up to 5,000 barrels daily refining capacity, a pump capacity of 1,000 g.p.m.: from 5,000 to 20,000 barrels, a pump capacity of 2,000 g.p.m.: and for over 20,000 barrels, a pump capacity of 3,000 g.p.m. Pumps should be installed in duplicate. When possible, two sources of power are recommended; such as one



motor-driven and one steam-driven pump. If entire reliance is placed on motor-driven pumps, stand-by service from an outside independent source of power is advisable.

Steam is very effective in fighting oil fires, and as a preventative. When it can be directed in such a way over the surface of burning oil as to be confined or held as a blanket, it will quickly smother the fire. If injected into tanks above the oil surface at times of risk, as during thunder storms or when adjacent tanks are on fire, it materially reduces the danger. The underwriters allow a 10 per cent. credit for a "steam jet" fed by a pipe not less than 2 inches in diameter. This clause is somewhat vague and the author suggests the installation of at least four  $1\frac{1}{4}$  inch inlets on all tanks over 80 feet in diameter, and one  $1\frac{1}{4}$  inlet for all smaller tanks. All flanges for steam pipes should be placed symmetrically just below the top angle iron of the tank. The supply pipe should be of suitable size to accommodate the jets, with control valves located so as to be accessible in case of fire. (See Fig. 254.) High steam pressure

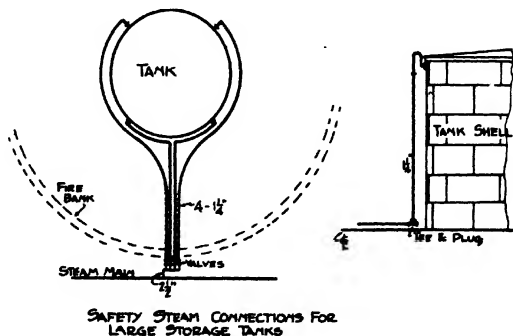


FIG. 254

Safety steam connections.

is not a necessity as long as the pressure is sufficient to insure an ample volume of flow. A rough approximation for the quantity of steam required as a preventative of tank fire is,  $16\frac{1}{2}$  pounds per hour for every 1,000 barrels of tank capacity; corresponding to about 30 boiler horsepower for a 55,000 barrel tank.

Efforts have long been made to smother oil fires by non-inflammable gas, but the difficulty is to retain such a gas over the fire. There has finally been developed a system, whereby salt and base solutions, to which some viscous material is added, are brought into contact with consequent formation of non-inflammable gas. This gas forms a foam of bubbles of the viscous solution. The foam is lighter than oil and can be floated across a burning oil surface in such a way as effectually to smother the fire.

Various combinations have been tried, most of them depending on the formation of carbonic acid gas when sodium bicarbonate and aluminum sulphate react together. For the viscous material, glue, glucose and licorice products are used. Glue deteriorates rapidly and is difficult to prepare. An excellent material now offered is "Foamite," a concentrated secondary licorice extract patented and sold by the "Foamite Firefoam Company," and used in their patented applications of foam for fire-fighting. In practice, two solutions are prepared, one containing the viscous material and bicarbonate of soda, the other containing aluminum sulphate. Formulas for their preparation with "Foamite" are:

Solution No. 1		Solution No. 2	
	Per Cent		Per Cent.
Foamite .....	3	Aluminum sulphate .....	11
Bicarbonate of soda ....	8	Water .....	89
Water .....	89		

All parts by weight

The two solutions, when brought together in equal parts, will form a foam (when fresh) whose volume is 7 to 8 times the combined original volumes of the two liquids. The amount of solutions necessary to foam, cover, and smother the fire from one square foot of burning oil surface is estimated at from 0.17 gallons of each liquid for tanks in a quiet atmosphere with no obstructions, up to 0.85 gallons or more of each liquid if the surface is broken up, or if there is a wind blowing over it.

At the above figures, the following amounts of each solution would be required for various sizes of standard tanks:

TABLE 69. FOAM REQUIREMENTS PER TANK

Tank Capacity (Bbl.)	Good Conditions,	Difficult Conditions,
	Gal.	Gal.
65,000 .....	1,760	7,800
55,000 .....	1,760	7,800
35,000 .....	1,220	6,100
30,000 .....	1,150	5,750
10,000 .....	390	1,950
5,000 .....	247	1,235

Accidents, such as those from broken lines, displaced hoods, or other causes, will occur at times, and a plentiful reserve of foam solutions should be kept in storage. The author recommends the following amounts of each solution for protection of the stated quantities of oil in storage:

Oil Storage (Bbl.)	Quantity of Each Solution (Gal)
Over 1,000,000 .....	125,000
500,000 to 1,000,000 .....	100,000
250,000 to 500,000 .....	65,000

Solution No. 2 is corrosive and steel tanks should not be used therefor without a lead lining. Wooden tanks (Fig. 255)

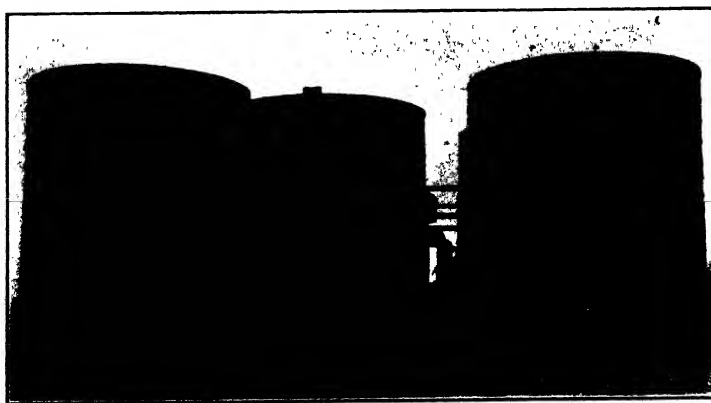


FIG. 255

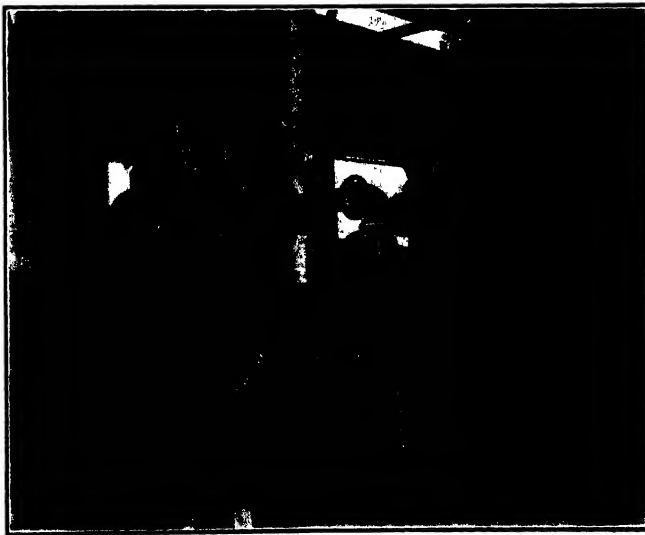
(Courtesy Foamite Firefoam Co.)

Foam pump station with solution tanks.

are suitable, but present practice favors lead-lining even wooden tanks for solution No. 2. If in climates where the solutions are

liable to freeze, provision must be made for heating the tanks. Direct steam in coils in the tanks is injurious to the solution on account of the high temperature. Hot water circulated through tank coils is better. On account of the corrosion from solution No. 2, coils will not last unless made of expensive material. For these reasons the ideal arrangement is to have the tanks in a building the temperature of which may be maintained above freezing.

Mixing is accomplished in small tanks, the chemicals being placed in solution therein, transferred to the storage tanks and the correct amount of water added, while agitating with air. Agitation should be used very sparingly to avoid evaporating water from the mixture, which may result in deposition of some of the salts. These go back into solution only with difficulty.



(Courtesy Foamite Firefoam Co.)

FIG. 256

Interior of foam pump station.

Periodical inspection of solutions is imperative. The practical test of efficacy is to add equal volumes of solutions No. 1 and

No. 2 in a graduate, when the volume of foam produced should not fall below 6 times the combined volumes of the two liquids. If it does, the solutions should be strengthened or renewed.

In applying the foam, each solution is pumped separately in equal quantities to a point directly adjacent to the fire, and the two are allowed to mix, expand and float over the surface of the oil. Pump capacities depend on the diameter of the largest tank to be protected on the basis of covering the entire surface in about 5 minutes under average conditions. Allowing 0.25 gallons of each solution as necessary for each square foot of surface, the pump capacities for each solution for various tank diameters follow:

TABLE 70. FOAM PUMP CAPACITIES

Largest Tank Protected: Diameter in Feet	Pump Capacity Each Solution: Gallons per Minute
120 .....	565
115 .....	520
93 .....	340
86 .....	285
54 .....	115
43 .....	75
30 .....	55

In selecting pumping equipment, care should be taken to obtain the above capacities at piston speeds around two-thirds the usual rating for general service pumps. Steam pumps are

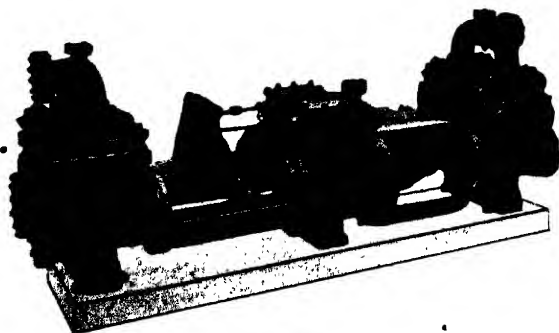


FIG. 257

Double end steam foam solution pump.

to be preferred, and the difficulties encountered in accurately pumping two liquids in equal volumes by two pumps or by the separate cylinders of an ordinary duplex pump have led to the design of the double end type with a steam cylinder mounted between (Fig. 257).

This type will involve a lower first cost than a fly wheel pumping engine, is reliable, and will accurately meter equal quantities of the two solutions. The fluid end which is used for handling the aluminum sulphate solution should be fitted with bronze cylinder liners, bronze pistons and bronze piston rods, while that handling the bicarbonate solution should be all iron fitted.

The distribution system should be so designed as to require only reasonable pump pressures. Block valves may be placed so as to cut out portions of the yard. These valves are to be left open and closed only in case of fire, to prevent the solutions from filling the mains in an unthreatened portion of the plant. Only genuine wrought iron pipe should be used for the main which carries the aluminum sulphate solution, No. 2. For solution No. 1, standard steel pipe is satisfactory. The system should include means for draining the lines after use. Where topographical conditions prevent ordinary drainage, connections for compressed air with which to blow the lines clear have proved effective. Under no conditions should the solutions be allowed to remain in the lines; not only on account of freezing, but also on account of the corrosion possible from solution No. 2.

The solutions should be carried in separate lines to the tank protected. Various methods have been used to introduce the liquids into the tank. One of the earlier designs is illustrated in Fig. 258. A pipe of 10 inches or 12 inches in diameter, or larger, was placed against the shell, and the liquids allowed to mix at the bottom, expand and spill over into the tank near the top of the shell. Later devices were automatic foam valves inside of the tank, discharging into a mixing pot which spilled the foam over and on to the oil surface. Automatic devices are not reliable and present practice prefers manual valve control.

The Foamite Firefoam Company, after much experimenting, recommended a chamber outside of the shell (Fig. 259) with manu-

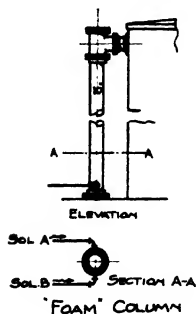


FIG. 258

Early pipe column  
for foam.



FIG. 259

"Foamite" mix-  
ing chamber applied  
to tank.

ally controlled valves, except in locations where valves would be inaccessible.

In all cases, care must be taken to keep all hoods, piping, and connections free from the roof in every way. Otherwise a possible initial explosion may remove the apparatus or render it useless.

The number of points of application of foam to a tank fire depends on the tank diameter. For tanks over 70 feet in diameter, two chambers are recommended, while for smaller tanks one will suffice.

After a fire the foam will gradually dissipate, and the resulting liquids will settle to the bottom of the tank and may be withdrawn.

In some of the earlier installations, baffles were provided in the tank to break up the fall of the foam. The theory was that an excessive drop would not only dissipate the foam, but

the foam would plunge under the surface and rise coated with oil. Fig. 259 illustrates such a baffle system. The Foamite Fire-foam Company, after many tests, now state that such baffles add nothing to the efficiency of the system and are only a source of unnecessary expense.

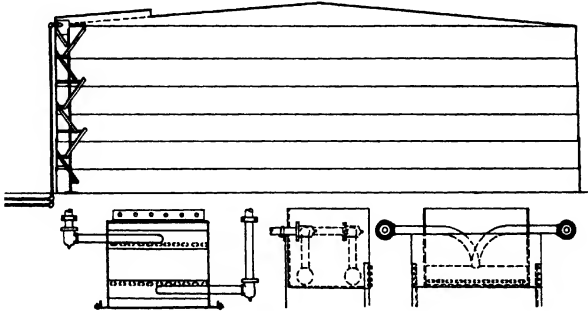


FIG. 260

Foam system with baffles and automatic tank valves.

Foam is also of use in fires around stills, barrel houses, filter plants and other departments. It may be thrown from a hose, and will cover and cling to burning objects, cooling and smother-

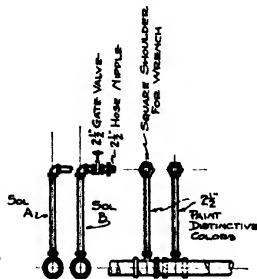


FIG. 261

Hydrant for foam fire streams.

ing the fire. Fig. 261 shows a foam hydrant. Two outlets are of course necessary, and two lines of hose must be used up to



a point close to the nozzle. Otherwise the foam would be broken down by friction in the single line of hose. A Siamese hose connection, with a short length of larger hose between it and the nozzle, is recommended. Fig. 262 shows the Firefoam hose arrangement. All hose used for foam should be rubber lined, and after use should be washed out with water.

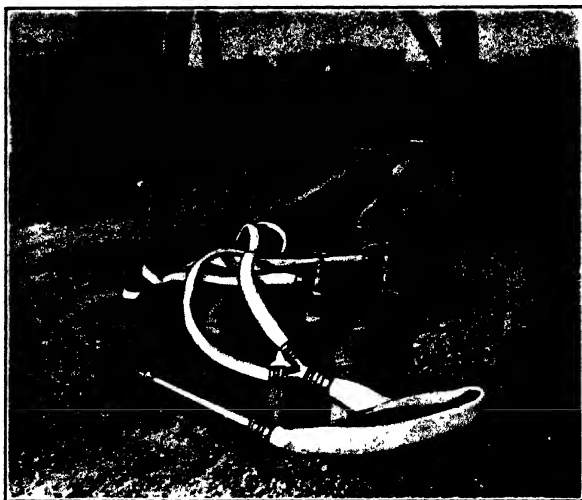


FIG. 262

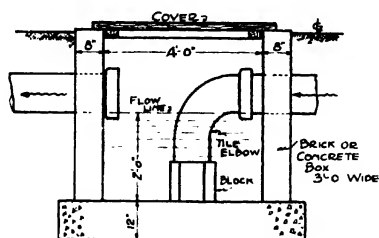
"Foamite" hose connections.

A forty gallon foam chemical engine mounted on wheels and charged with the two liquids may be obtained. This is effective for small fires, often obviating the necessity of starting up the main system. Extinguishers of the underwriter type are also manufactured.

Savings on insurance premiums, while marked, do not always carry the investment charge on a foam system. The idle time and loss of operating profits due to fires should be considered when analyzing the benefit from the system.\* In the writer's

opinion, there are very few cases where some kind of foam protection is not warranted in an oil yard.

While not essentially part of a fire protection system, attention should be called to the necessity of adequate sewer or drainage capacity. With several fire streams concentrated in a small part of the plant, unless the sewers or underdrains are of ample size, the water is liable to back up above the ground surface, and burning oil may thus be carried to other structures. This precaution is particularly necessary around the stills of a refinery. Sewers should also be trapped to prevent a possible "flash back" to other sections of the plant. Fig. 263 shows an inexpensive but effective device of this kind.



FIRE TRAP FOR SEWER LINES

FIG. 263

Fire banks and fire walls around tanks and dangerous sections of a plant are largely used. Around tanks, space permitting, earthen dykes are customary. The impounding volume within such dyke should not be less than one and one-half times the capacity of the tank or tanks which are to be protected. A top width of 4 feet is recommended as a minimum, especially around tanks on a refinery site where the tops will be used as convenient pathways. The danger from burning oil tanks is increased by the tendency of certain oils to "boil over." This is due to the water sometimes present, which gradually becomes hot enough to boil and generate steam. The time required to reach this point varies with different oils. In the case of heavy oils such as Mexican, which has some water in suspension, a

fire will after six hours develop this danger. Other crudes take eight or twelve hours. Fire guards are therefore essential for crude or heavy oils containing moisture. With distilled and finished stocks there is little danger of a tank "boiling over." Concrete or brick fire walls 3 or 4 feet high around each battery of stills is a worthwhile precaution. In case of a ruptured still bottom, the oil is confined to one area and may be conveyed to the sewers by conveniently located catch basins.

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